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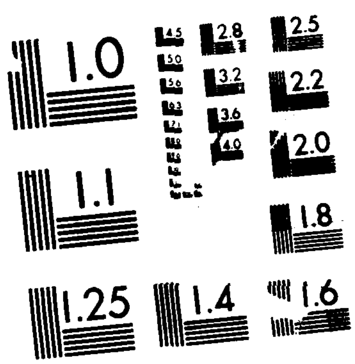

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SHORT-TERM SOLUTIONS TO PREVENT SIMULATOR-INDUCED MOTION SICKNESS: REPORT OF A CONFERENCE

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On September 21-28, 1985, a conference was held at Pensacola, Florida, for the purpose of determining a model of simulator-induced motion sickness. A total of 17 scientists, with expertise in areas related to the study of motion sickness and its treatment, were in attendance. The scientists were asked to address a variety of questions which had been previously prepared by the conference conveners, and were individually deposed in a quasi-legal manner in the presence of a court reporter. From these depositions a set of guidelines and recommendations have been proposed as short-term approaches to limiting the severity of the problem until longer term solutions can be experimentally validated.

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INTRODUCTION

The use of simulation in aviation training continues to increase due to factors which have placed limits on more traditional forms of training such as safety, aircraft availability, cost, and maintenance. Simulators permit practice of a variety of tasks, such as emergency procedures, which cannot be conducted safely, or well, in the aircraft, and can provide a variety of training options such as playback, freeze, and performance measurement and recording. Technologically advanced simulators for training vehicular control skills are becoming increasingly commonplace.

Unfortunately, an increased incidence of simulator sickness and the occurrence of related perceptual aftereffects has accompanied the increased sophistication of ground-based flight trainers (Kennedy, Berbaum, Lilienthal, Dunlap, & Mulligan, 1987). Simulator sickness is generally manifested by symptoms that are characteristic of motion sickness (e.g., lethargy, nausea, emesis), but includes others which generally are not (e.g., eyestrain, headache, dizziness). Perceptual aftereffects include sensations of climbing and turning while watching television, and 180-degree inversions of the visual field (Kellogg, Castore, & Coward, 1980).

There are several obvious disadvantages of simulator sickness for training. Aircrew lack of confidence in the training may promote disuse. Furthermore, it may be necessary to limit subsequent flight activities if aftereffects are sufficiently disturbing. This, in turn, may limit overall *operational effectiveness.* Simulator aftereffects may place the person directly at risk in other post-training activities (e.g., driving).

As part of a research and development program into the causes and prevention of simulator sickness, a conference was convened to devise ways to alleviate simulator sickness. Internationally recognized experts in other forms of motion sickness research were assembled (see Table 1). Most were actively involved in investigations of perturbations of the inertial environment of an individual, particularly those where linear and angular accelerations are discordant such as in weightlessness, or during aerobatic maneuvers in aircraft. Participants were engineers, physicians, physiologists, and psychologists who were familiar with the organs of equilibrium and the inertial environments which stimulate them. They were also aware of the attributes of visual inputs which commonly accompany these vestibular stimuli. Collectively, the participants had an extensive knowledge of the conditions that are conducive to motion sickness, and some experience in suggesting how it might be alleviated.

No formal preparation was required of the participants prior to the conference other than careful consideration of a series of questions (see Appendix A). These questions, formulated by the conveners, ranged widely over the issues to be discussed, and served to direct discussions. Although participants were encouraged to address questions with which they felt most comfortable, the more controversial questions were not avoided. Whenever there was a lull in the discussions, or a desire to leave a topic, a new question was brought up. After questioning began, one of the three conference conveners pursued the line of inquiry and followed worthwhile leads.

TABLE 1. PENSACOLA CONFERENCE PARTICIPANTS

NAME	AFFILIATION	LOCATION
Benson, Dr. Alan*	RAF Institute of Aviation Medicine	Farnborough, Hants, England
Berbaum, Dr. Kevin S.	Essex Corporation	Orlando, Florida
Chambers, Mr. Walter S.	Naval Training Systems Center	Orlando, Florida
Crampton, Dr. George	Wright State University	Dayton, Ohio
Dobie, Dr. Thomas	Naval Biodynamics Laboratory	New Orleans, Louisiana
Dunlap, Dr. William P.	Essex Corporation	Orlando, Florida
Ebenholtz, Dr. S. W.	State University of New York College of Optometry	New York, New York
Guedry, Dr. Frederick	Naval Aerospace Medical Research Laboratory	Pensacola, Florida
Jex, Mr. Henry R.	Systems Technology, Inc.	Hawthorne, California
Kennedy, Dr. Robert S.	Essex Corporation	Orlando, Florida
Leibowitz, Dr. H. W.	Pennsylvania State University	University Park, PA
Merkle, Mr. P. Jay	Essex Corporation	Orlando, Florida
Money, Dr. Kenneth E.*	Defense & Civil Institute of Environmental Medicine	Downsview, Ontario, CAN
Oman, Dr. Charles M.*	Massachusetts Institute of Technology	Cambridge, MA
Parker, Dr. Donald	University of Miami	Oxford, Ohio
Reschke, Dr. Millard	NASA, Johnson Space Center	Houston, Texas
Welch, Dr. Robert B.	University of Kansas	Lawrence, Kansas
Whiteside, Dr. T. C. D.	Anthromec Consultancy	Argyll, Scotland
Wilkes, Mr. Robert L.	Essex Corporation	Orlando, Florida
Young, Dr. Laurence	Massachusetts Institute of Technology	Cambridge, Mass.

*Met separately in Orlando

A certified court reporter was present during the discussions, which took the form of legal depositions and generally lasted for two to three hours in the morning and slightly longer in the afternoon. Evenings were spent in prediscussion of the next day's topics. The presence of a court reporter served to formalize the proceedings and we believe the respondents tended to be more disciplined in their language usage. A transcript was available within one week of the conference as both a deliverable product to the sponsors of the forum and a record for the conveners whose task was to integrate this information.

The meeting was held in Pensacola, Florida. In order to maximize participants' attention to the task at hand, no one had automobiles and all meals were taken on the premises. During free time the participants generally talked with one another about the scientific business which brought them there.

Although the discussions were wide ranging in terms of the topics that were dealt with, the primary emphasis was on formulating a series of recommendations for preventing the occurrence or alleviating the severity of simulator sickness. What follows is a partial summary of those recommendations. Readers desiring a more thorough treatment are referred to Kennedy et al. (1987).

Factors that surfaced at the conference which are believed to influence simulator sickness and which could be modified in the near term entailed: a) changes in simulator usage; or b) capitalizing on the awareness of the instructor and adaptability of the operator. Longer term engineering design changes in simulators will require research into the aetiology of simulator sickness. These efforts may include: a) examining whether sustained motion cueing could be substituted for transient motions; b) monitoring motion profiles of simulator flights to provide warnings of nauseogenic conditions; c) analytic decomposition and determination of the characteristics of the visual imagery necessary for perceived self-motion; d) elimination of cue asynchrony; and e) avoidance of visual delays and lags.

CHAPTER I

Discussion with Thomas C. D. Whiteside, M. D.
September 23, 1985 - Morning Session

1. Sensory Conflict and Conceptual Behavioral Models (CBMs)

DR. DUNLAP: Do you think there are any competitors for the sensory mismatch theory?

DR. WHITESIDE: No. If we start off with the conceptual behavioral model (CBM), which is a phrase that I've used, I'm saying basically that the mismatch question, or whatever you wish to call it, is not just a comparison of a vestibulo-ocular response, with that which you would expect, but it's the comparison of an entire behavioral model. This behavioral model contains conscious and unconscious elements, which contains psychoso- matic responses, which are sensorimotor, and some of which are vegetative and some of which are cognitive.

Now the very fact that it contains elements of which one may well be unaware consciously means that it is very easy for the mismatch to take place without one being quite aware what the mismatch is due to.

It seems to me that the conceptual behavioral model is produced as a result of the fundamental drive for stimuli from the environment. If the model cannot be compared, or if it cannot be updated, the collection of symptoms usually associated with sensory deprivation appear as internal restlessness. It seems to me that motion sickness is one specific element of this which doesn't, in fact, detract from Treisman's idea that it may have some developmental link with expelling poisons, because obviously, if you do get poisons, you can often get the symptomatology that you get from motion sickness. So really, I think it's compatible with that concept.

What I'm suggesting is that in taking any information from a flight simulator and comparing it with what is experienced, if the two don't agree -- and especially if the lack of agreement is in an unrecognized area -- then nausea may develop.

DR. KENNEDY: Would it be better for the study of how the organism handles conflicts rather than sickness per se, to think of motion sickness as merely a by-product, an outcome, that happens under a certain set of circumstances?

DR. WHITESIDE: I would agree that conflicts could well be the starting point.

The conceptual behavioral model, which we can call Con-BT or Con-B model, comprises a pattern of hierarchical sensory and motor synergic responses.

Now it's hierarchical, which means that some are less important and superficial, and maybe later than the other ones, and they are also psychosomatic in nature. One of the factors -- if you look at motion sickness from the psycho or somatic, the "psycho" bit comprises fear or anxiety or apprehension -- probably apprehension. It may be apprehension about being motion sick. It may be apprehension as to not performing so well, or it may be just like a little boy going to the dentist who is apprehensive of what's going to happen when he arrives. So the moment you start getting your mismatch, there is some apprehension which builds up, and that can really distort it completely, because it makes the whole thing worse once you're in a runaway control system.

The other element worth considering is the vegetative response. You can decondition the psycho part of the response (the anxiety) by experience and by training. But deconditioning the vegetative response is, of course, much more difficult, although not impossible. So you can get some adaptation to the vegetative response, which produces greater tolerance, or you may be able to decondition it to some extent, much the same way as various techniques can control the autonomic nervous system, like heart rate, through breathing techniques, techniques implying biofeedback, but biofeedback of a cognitive nature. It's got to be cognitive. You've got to know how to control it and that you're applying it to a specific situation. So cognitive in this sense -- that's what I mean by biofeedback.

Generally speaking, if the mismatch is in the same general direction, there's probably a greater acceptance than if it is specifically wrong. For example, if the visual information comes before the vestibular information, in one instance, whereas one has learned from experience in the real world that they come in the other relationships, opposite temporal relationship, then this is going to make one very happy, although one may not be able to identify. It's almost like looking at a movie from a distance and actually hearing the voice before seeing the lips move. The opposite one is accustomed to, because of the time delay, the transmission of the sound. That's okay, within limits. But I think if you push that one around the other way, you could be in trouble.

2. Cognitive Theory

DR. WHITESIDE: The very last point is this: In some situations you get a trained person who is motion sick and you train a person to resist motion sickness by various techniques, and then you expose him to the live situation and to the simulation and he gets sick. Why does he get sick? I think it's because the training has to address itself to explaining to the individual what's involved, so you're really tackling the thing at the grass roots. The objective in the desensitization to somebody of motion sickness would be to go to the roots of the problem as far as that individual is concerned, treat it in a cognitive manner using biofeedback and so forth where necessary to try to produce extinctions of unwanted responses, but really taking it radically to its origins, so that when the individual is then exposed to a situation that he has not handled before -- let us say he's in microgravity or he's in a ship of one size, he gets a different kind of motion. He gets a different type of mismatch. But if he's been trained to, on a radical level, he would then be more readily able to rationalize his situation and to understand it. In other words, 'I am not going to get worried about this. I can handle all kinds of mismatch so I have no problems with that. I may have some nausea because of the vegetative physiological responses, but that's not going to worry me. If I bring up [throw up], it will be finished but it's not going to worry me. My training that I've had in the modification of vestibular responses, of vegetative responses plus the adaptation that I've had through my training, are going to enable me to handle this so that I can perform with very little decrement.'

Now that's the sort of basic approach I would aim at in the training. The training can be of two types. It can be progressive or it can be flooding or avalanche. I'm talking in behavior medicine techniques. So you can do a flooding, which means that you expose the guy to a terrible situation and he has a difficult time, but you can get an abrupt change or you can do it more gradually. There are advantages to the unpleasant way of doing it in that, of course, it takes a lot less time. It can be done with simple equipment.

3. Realism: Perceptual vs Procedural Training

DR. WHITESIDE: The last point I might make is that I'm really wondering whether one should go for simulation to such a degree. Maybe one is actually making things worse by making the thing more realistic because it never actually is the real situation. The odd clue can be missed for a training person, he suddenly misses it in his conceptual behavioral model, and bang, you've got the onset of the motion sickness conflict. So maybe the answer might be to use the simulators as procedural trainers and to say we will also introduce some small elements of motion and so forth, just to give some idea, but that this is not the real thing. And furthermore, it doesn't look like the thing and maybe that's good.

If you go into the simulator, the person thinks that if it looks real, it is real, but if it doesn't look real he may be less sick. That's it. I'm ready to answer any questions.

DR. KENNEDY: It's been argued that simulators that exist achieve their benefit by teaching procedures. It's also been argued that new simulators are going to teach people how they can modify their percepts rather than just procedures. Do you think that this is going to do what you just said? Should we stop trying to teach percepts?

DR. WHITESIDE: I'm not sure I understand that. Can you amplify on percepts?

DR. KENNEDY: What they would like to teach is how to recognize an airplane at a certain distance, and which way it's going, and the difference between two or three different types of airplanes. That's not motor learning. That not 'where are the switches and what are the knobs and dials?' It's not stick feel. It's not motor learning. It's perceptual learning. I believe, and I'm wondering if you believe, that the quest for perceptual learning in a simulator may be leading to a quest for high fidelity, high realism which, in turn, may make narrower tolerances and thus more sickness?

DR. WHITESIDE: Yes. In fact, this is really what I'm saying. We've done it this way for so long maybe we're just going the wrong way. So if we make it into a procedural simulator, which is the interactions with the environment, the machine environment, then the perceptual training can be done separately.

DR. KENNEDY: In the airplane, where the pilots want to do it anyway.

DR. WHITESIDE: Yes, you can do it anywhere, best of all in the aircraft. Or if it's not convenient or it's too expensive to do it in the aircraft, you can design a test to reproduce it on the ground. If you make the perceptual training techniques simple you're much less likely to get wrong information transferred to the live situation, because one of the problems of simulators is that you can transfer wrong training to the live situation. But if you limit it, suppose you have your simple aircraft recognition or whatever different attitudes, that can be easily transferred to the live situation.

DR. BERBAUM: Some of the percepts that presumably should be trained in the simulators are things like the appearance of the entire visual field as you are making a particular maneuver. For example, if you are turning your plane into a bombing run, where will the target appear within the visual field? Namely, the top. This is a rather complex visual array.

DR. WHITESIDE: That's right. There are advanced combat simulators which can do all this, but you could actually do that with a much simpler optical projection device onto an inside dome. That brings in an important point, and that is the attitude of the scene that you're looking at in relation to your resultant "G." If the visual scene is as we see it routinely, we're accustomed to that, but if this whole table were inverted by mirrors, I think most of us would feel momentarily a bit disoriented. We know it's an experiment but we would still feel odd. One of the changes would be the respiratory change. There would be a pulse rate change, signs of a mismatch or of a conflict situation which you're trying to resolve. The way you resolve that, of course, is that you have to start again interacting with your environment in order to judge where the distances are to get feedback from it.

So once you've done that you can understand, put in a new interface on your conceptual behavioral model, and say 'This is a simulator, okay; I know that this is a situation that's being carried out in a room, but it's teaching me something that might arise in flight.' So you get accustomed to not being anxious if the relationship of the perceptual vertical does not necessarily agree with the usual framework of what you're observing.

4. Adaptation and the Flooding Technique

DR. DUNLAP: But part of your suggestion on how to beat the problem is to train people to adapt quickly and we're talking about vegetative responses. Can they be trained?

DR. WHITESIDE: No. I was talking about flooding in relation to the "psycho" part of it, the anxiety. The vegetative responses you can modify probably by biofeedback techniques. I doubt whether you can extinguish them completely because they're pretty fundamental -- the libertation of histamine -- which is why the bit that responds to pharmacology is really the vegetative side.

Some of the medications implied also have effects on alertness so they may also affect the psychological side of the thing, as far as anxiety is concerned, but that is very amenable to training and that you could flood out. Undoubtedly, the fear of the problem is a marked phenomenon and it varies according to the personality of the individual. Some people have no fear of the environment and they will tolerate a tremendous amount of vestibular mismatch -- vestibular stimulation producing mismatch and so forth. Other people will tolerate very much less. Some people will be made sick by a purely visual mismatch without any labyrinthine stuff. Other people need a strong stimulus like the Coriolis.

DR. BERBAUM: As I understand you, sickness may be modifiable by giving cognitive information, telling the person what to expect.

DR. WHITESIDE: Yes. It is also modifiable by putting the individual into an environment from which he cannot escape. He cannot get his usual pills. He cannot get away from it. If he is going to be ill, he's going to be ill. That's it. If he thinks he's going to die, that's it. He cannot get away from it and he's kept in that.

MR. JEX: As onboard ship.

DR. WHITESIDE: As onboard ship. I have a case in point. A person who was very sensitive to motion sickness of all kinds was exposed to a situation *in which there was no escape* from the environment, in fact, he had to stay in the vessel long after he had wanted to escape. There was just no way he could get out. He didn't have all his usual things that he associated with his deconditioning. This is one of the problems in doing a progressive deconditioning. You may latch on to one of the things that are being used and you need that to get your relaxation or your freedom from anxiety. But none of these things were available, the soda water that usually helped him, the pills that he usually took, he just felt as if he were dying. But he eventually went to sleep and he was never sick again. He used to have migraines; he never had headaches again. He used to be afraid of being seasick and since that time he has never been afraid of being seasick at all. So he tolerates motion tremendously. He's never been sick. Occasionally, he experiences some nausea, but it doesn't worry him. He's not afraid of the thing that's going to happen.

DR. BERBAUM: And what is the fundamental change that has occurred?

DR. WHITESIDE: It's been as a result of the flooding technique. The anxiety as to personal ability to cope with a problem has been removed and, therefore, on any future occasion. He coped with what he thought was completely impossible.

DR. KENNEDY: Is this a "right of passage?"

DR. WHITESIDE: One way of doing it, yes. It was a way of finding out which person was sick and which wasn't, but you're really effective doing a test which probably involved the whole personality of the individual. You're throwing out the people who collapse under it. But you can use that same thing to extinguish conditioned responses that have been built up in the individual's behavior pattern.

5. Predicting Who Will Get Sick - Physiological Measures

DR. DUNLAP: Do you feel you can predict, prior to getting in the simulator, who is likely to get sick and who isn't?

DR. WHITESIDE: Yes, I think so. One of the things I would suggest looking at would be the autonomic responses to anxiety -- things like PGR, breathing rate changes, the usual techniques -- the usual symptoms that you look for as a sign of stress in somebody who is under a lie detection test. You get normal responses and then you get people who respond much more. The hierarchies of those responses may have an individual fingerprint for each person. So one person may respond more with PGR, start sweating, and another person may respond more with altered respiratory rates.

But I would guess that it's probably possible to examine a number of people and see if indeed, there is a pattern in the hierarchical response. My gut feeling is that sweat rate, or PGR, might well be one of the important predictors; that or respiration change.

MR. JEX: What would the forcing function be?, What would the excitation be that you were measuring the response to?

DR. WHITESIDE: Perhaps putting somebody in a slowing rotating thing, just producing a Coriolis stimulus. Keep your head still. You're going to feel the acceleration up and so forth. So you would get your responses from the moment the person went in, and you briefed him what you were going to do while the thing was stationary. You would get all the changes in sweat rate before the thing took place and then when it took place. Maybe you would do it twice, so that from some experience they know what it's like and they know whether they can handle it or not. So the second time you do it either they will settle down and can handle it or else they're terrified.

MR. JEX: Dr. Whiteside, one of the things that people see in other areas of stress, indications such as heart rate, in first encounters or early encounters have these high anticipatory heart rates which often decrease and at subsequent encounters are less and less. Is there a similar effect on some of these symptoms of malaise (nausea) that come from first and second encounters with, say, chair or head motion?

DR. WHITESIDE: Yes. That's exactly why I was suggesting two encounters, because on the first you get peaky responses which may not indicate anything other than that the chap is naturally a bit tense in encountering a new situation. It may not be a new situation, but he doesn't know until he has actually experienced it, 'What are these guys going to do to me?'

MR. JEX: So the intrinsic personal consolation of sensitivities is best revealed on a second or third encounter.

DR. WHITESIDE: That's right. I think also, possibly giving some positive feedback to the person, because he requires feedback. This is how we are all communicating with our external environment and judging our performance, on the basis of the feedback we're getting either from how we've coped or from how we've interacted with the environment. If nothing is happening, we inject a disturbance signal into the environment and we watch what comes back.

DR. KENNEDY: Why would some of us get sick with a Coriolis stimulus and less with a linear oscillation stimulus, and the converse? In other words, do I have a personal conflict for Coriolis and less of one for linear oscillation?

DR. WHITESIDE: Might it be that the Coriolis produces bigger psychological vegetative upset than the linear acceleration change? So some people whose psychosomatic or psychophysiological response is more importantly based on the physiological response may be affected more by that or less by that whereas the psychological response, if that's dominant, might well be affected by the fact of linear acceleration, or a decrease of linear G, microgravity, which they had never experienced before for any length of time. So they do a Keplerian trajectory and they get zero G, or microgravity, for one, two, or three minutes, whatever is available, but they've never experienced it for any length of time in which they've had to move about. Also, in that situation as I've said, you've got the actual G reference framework of your visual field and getting that tilted around and become acclimatized to not handling it in relation to normal perceived gravity.

DR. KENNEDY: So aside from practice, you would say that an individual's susceptibility to one environment versus another is more on the response side than on the perceptual, receiving, comparing, or template matching side?

DR. WHITESIDE: Yes, I think it's probably peculiar to each person, some putting more accent on the psychological stress and some putting more accent on the physiological stress.

6. Generalized Deconditioning Psychological Responses

DR. BERBAUM: Tom [Dr. Whiteside], you were talking a few moments ago about flooding. It seems to be a generalized deconditioning of the unconscious psychological responses. How far do you expect that to generalize? If you could take a class of airmen and expose them such that you obtained this generalized kind of deconditioning, you have to redo your predictative tests of who is going to get sick in a simulator, because the order of people may be quite different. For your example, you have a very sensitive person who is very likely to get sick, who goes through a deconditioning experience and ends up being very resistant to motion sickness, perhaps even more resistant to motion sickness than other individuals who were originally less sensitive than he, before the desensitizing experience. My question is do you have to repeat your test?

DR. WHITESIDE: If you've got people who actually require deconditioning for extinction of anxiety responses you've got to train them by flooding or whatever so as to cope with that. Then you do the test to determine how well they respond. So, that is correct.

Obviously, you're starting from scratch. You have several participants who come up for some kind of training that haven't been trained at all; these are raw recruits for the job. Well, clearly, if you can sort out who's got a psychological response to the thing, you select out those individuals if you have enough people to choose from because you won't need to spend time deconditioning them. There's always the theoretical possibility that the deconditioning itself may have a sort of temporal hierarchical nature, like any form of learning. The most recently acquired learning under stress may be the one to go first. I think that with the type thing we're talking about, the flooding technique (producing extinction of psychological anxiety, for example), you've trained the person's personality. You've really not put him in a learning situation but you've assured him, inside himself, that he is able to cope with this problem. It's like the person who has an alcohol problem or a cigarette smoking problem and he makes sure his wife locks up all the alcohol and that he never gets any cigarettes. Then he starts eating sweeties to cope with the desire for these things. He's going to break down in no time flat. He's going to break down if there's a bottle left unattended and if he's on his own in the house, he will start drinking. But if you can extinguish the desire for the alcohol so that he is aware, himself, that I do not want to go through with this, I really do not like this stuff, and it's wasting an awful lot of money and time, I'm switched off half the time and I don't want to go back to that in any way, shape or form, you can leave the stuff lying out. You don't lock it up, because as I say, it might get accidentally unlocked. So you leave the things that you're trying to decondition the person from, you leave them about so that they're still there. But the thing is, now you can cope with them being there and this person can cope with the fear. He knows he's not going to be frightened about whether he can actually cope with the thing or not.

MR. JEX: You started out earlier by using biofeedback conditioning also in the same sense. Could you elaborate a little more on that? What kinds of feedbacks would you use, and what measures would have the person look at to extinguish to increase resistance to motion sickness.

DR. WHITESIDE: For example, relaxation therapy: heart rate, heart control with respiration. You tell the person, 'You get the rhythm of the pulse, you feel it regular, okay? Now take a deep breath, hold it, and observe that your pulse rate is slowing down. Let the breath out slowly and you'll find it will stay slow like that.' That slowing of the vegetative response is actually accompanied by a general relaxation and other demands on you may be giving them feedback. Show what's happening to the PGR or to something else.

MR. JEX: But all the while he's undergoing the environmental motions -- is that the idea?

DR. WHITESIDE: Yes, you could say that. You explain to the person how it's going to work and then you say, right, we're going to give you a simple Coriolis stimulus, a simple acceleration, angular acceleration, and a rapid start, and we're going to measure your skin response, the resistance of your skin. This will be displayed on a meter in front of you. Now, if you keep your head still, you will get a purer, predictable stimulus. We will increase this amount and you will see that your response -- now we're going to do it again. This time, try to relax. You know you're going to be able to cope with it, and you'll find you're relaxed, you're not going to be afraid of the outcome. We will not take you beyond the level that you can cope with. So you establish in the person's own concept; his cognitive faculties know that he can cope with the thing. He can see it. Then you increase the thing. You should be able to go up pretty high. You should now be able to cope with a very fast acceleration and start and so forth.

Then the person gets interested and says yes, that's great. I have never coped with this before. Can I get some Coriolis effect to really make it bizarre? Then you get a strong stimulus. Then you say, yes, but it may make you feel ill but you're going to cope with feeling ill because you've got the vegetative response which is a perfectly normal one. But don't be afraid. If you feel ill, you'll find that you're coping with it okay, and you'll be tolerating it much more. Then in that prospect you are deconditioning the psychological -- the anxiety the person has had with the thing -- but by cognitive feedback, at the time, relating to the thing he's doing. But again, being careful, being very, very careful indeed, not to relate it to that simulator. Because all the way through you've got to say we're really getting down to the grass roots here, and all we're doing is giving you the ability, showing you that you can cope with conflicting perceptual behavioral models. You're going to get a conflicting conceptual behavioral model for some situation that you haven't encountered before. When that happens, you're going to fall back on this training and you're going to say, okay, I know what's happening. I'm feeling a bit curious. My respiration has changed. I'm not quite happy, but I can cope, because I've had this marvelous training.

DR. KENNEDY: Do you think that is a viable approach to simulator sickness?

DR. WHITESIDE: Yes, I do.

DR. KENNEDY: Do you think training, in general, is a viable approach to simulator sickness?

DR. WHITESIDE: Yes.

DR. KENNEDY: Is it all right to adapt to the simulator?

DR. WHITESIDE: Yes. You can train somebody to cope with simulator sickness, but I think the correct approach is not to use a simulator in that way, not to have a simulator that is going to produce sickness. In other words, make your simulator such that it is clearly not the same as a ship. That is, it is clearly not the same as an airplane. Don't bother closing the thing in and putting in noises of wheels rumbling and so forth, and take off, and the tilt. It's not necessary. In fact, I think it contributes to the motion sickness syndrome by producing a CBM which is not related to the CBM of the real situation--conceptual behavioral model.

7. CBMs, Training and Realism

DR. BERBAUM: I would like to talk a little bit more about your idea of CBM (conceptual behavioral model) in terms of simulator sickness in pilots and in novices. The CBM notion bears some kinship with some earlier ideas of people like Bartlett, Gregory, and Minsk. How do these CBMs, schemeas, frames get evoked? How many of them can be maintained simultaneously? You make a point in your introductory statement that for pilots they have a well established CBM for particular aircraft and the key to keeping them from being sick may be to develop a separate and complete CBM for a simulator particularly.

DR. WHITESIDE: Yes.

DR. BERBAUM: Of course, this notion is not going to work nearly so well for novices, because they don't have a CBM to begin with, and they would be, perhaps, trying to learn two CBMs simultaneously. Can you address some of those questions?

DR. WHITESIDE: I mean that very definitely, that rather than have two CBMs that are almost the same, so you've got problems in working out -- if we're talking about a trained person -- as I said, you make them distinctly different so that you go in that simulator and you know it's a simulator you're going to. You're never going to mistake this for an airplane. So, in other words, make the thing less "realistic." Don't spend a lot of money painting the thing and all, and having the noises, etc., and the aircraft smells. Make it such that this is a simulator. Okay, we're going in a simulator. You go through your procedural, your learning procedures, and so forth. If you want your perceptual learning, you go to some other thing.

DR. BERBAUM: Couldn't you as an alternative to that have a very realistic simulator which included a stimulus that allowed the discrimination to be quite clear? In other words, suppose you had a terribly realistic simulator, except for some visual vestibular mismatch problems or something of that nature, but then you put a red haze over everything such that the current condition could be easily discriminated.

DR. WHITESIDE: Yes, I suppose you could do that. The hazard is that where two CBMs are close together, close to one another, you may get a negative transfer to the wrong situation. That's a different way. A negative transfer is something you weren't aware of. If you're aware of it, no problem. But if it's one of these effects that you don't know about because you've never actually thought about it, and it's actually there, because bear in mind, what applies very much to the person in the simulator is the ability to diagnose what is matching and what is not matching just in the same way as we explain things in terms of what we are familiar. So if the person is not familiar with the fact that what actually is wrong in this thing that he's got is that the time of the proprioceptive responses is not in accord with the time of visual responses as they would occur in a real live situation, he may not be aware that that's the difference, and consequently he gets -- he can land the wrong way, and there may be a negative transfer to real flight where he does something completely wrong.

8. Symptoms Result From the Mismatch of 2 CBMs

DR. BERBAUM: In other words, you're saying that what you may end up doing is producing less simulator sickness and more actual airplane sickness.

DR. WHITESIDE: No. I'm addressing the problem, primarily, of producing less sickness. I'm saying that the sickness is a response of the mismatch between the two CBMs. So, therefore, I'm saying if you make the two CBMs markedly different, so there's no confusion between them, so you're not really trying to match one with the other, then you eliminate the sickness. You also eliminate the possible negative transfer to the other CBM because you don't go into a transfer in the other CBM, except in certain selected areas such as procedure. I'm going to take the procedure module out of my simulator CBM and I'm going to plug it into my real flight CBM. I can do that, you know.

MR. JEX: Could we carry that a point further? Would you then draw from that point of view a conclusion that a fixed base simulator, which didn't attempt to put any motion environment on the trainee, would be just as effective as a moving simulator that might have gross distortions of the motion cues because of the motion limitations? In other words, don't give them any miscue rather than the wrong one.

DR. WHITESIDE: If you've got a fixed base simulation and you've got a very good visual display, high resolution, wide angle, you could be in the same boat because you've got the visual stuff that's very realistic. Indeed, you know what it's like. You stand in one of these things in a fixed base and you're looking at the thing. Then, suddenly, you go into a steep right bank, or else you land and you put the best thrust on, tremendously, and the whole thing stops. You stop feeling sick because you're not getting any pitch forward.

9. The Possibility of Vestibular Masking

DR. KENNEDY: Would you comment on using bumps to fool a vestibular system into thinking it's flying as a method for getting around that problem? Not necessarily bumps concordant with what you would get in flight, but just enough to have the vestibular system imply that it's not at rest. For instance, in a fixed base simulator, if sickness were a problem, for some of the visual induction reasons that you mentioned, could you use a G seat or a shaker seat to create the impression of an inertial input; sort of a vestibular noise?

DR. WHITESIDE: I think so, provided the other bits were not too real. If the visual really looks like a computer generated picture, if it's very artificial, it can nonetheless contain the elements of the visual scene which are required to train the person. So you've got the horizon and other items. You have bright green ground and a bright blue sky, or whatever, lines going up to a vanishing point, and you have crosswire hatching like the flight analogue presentation.

10. Symbology Rather Than Realism: Correct Dynamic Relationships

DR. WHITESIDE: That has the advantage that you are applying the symbology, which the brain can identify, and the brain also knows that this is a simulation, it's not real. But at the same time, what it does is it allows him to identify and cope with that in various upside-down and unusual configurations, for example. You can learn to relate that to the control responses. So you are learning procedures without introducing realism, which could be confused with a real situation. Now, in that environment, you could then easily introduce some elements of proprioceptive or acoustic information, providing it's also kept at a level which is merely indicative that this is symbolic.

DR. KENNEDY: Keep the switch in the open position.

DR. WHITESIDE: That's right.

MR. JEX: Cueing rather than realism.

DR. WHITESIDE: Exactly. I like that -- cueing rather than realism. I'm suggesting that there is the sort of symbology which can be meaningful to the individual as long as it's in the right relationship.

MR. JEX: And we would say the right dynamic relationship is there.

DR. WHITESIDE: Right.

MR. JEX: So you learn the right dynamic behavior.

DR. WHITESIDE: That's it.

MR. JEX: You're saying train for behavior rather than realism.

DR. WHITESIDE: That's right. You don't need to have the edges with a high resolution. You don't need to have markings on the runway as you're going along.

11. Identifying Cues to Simulate

DR. BERBAUM: Let me ask one follow-up question. Is there any way of getting to those aspects of the visual environment that need to be symbolized within the simulator? To create a useful simulator from the point of view of visual training, you have to include those aspects that are critical for flying the airplane. Is there a methodology whereby you can decide what aspects to include? The reason why people are going for such realism is because, basically, they don't know what it is that is necessary to learn to fly an airplane. But they do know that if they can make it exactly like the real world, then it can be used for training. For the idea of cueing, rather than simply realism to make sense to the people who are making decisions about simulators, you have to have a methodology whereby you can identify relevant attributes to simulate such that you have a viable alternative.

DR. WHITESIDE: You've got a problem because, as you know, the specifications of a lot of these devices come from operational requirements people and they don't, as you say correctly, know what is needed.

It's an odd situation. It's bad enough with trained psychologists to work out what the requirements are, but to leave it to the purely operational side who don't have that knowledge, is crazy. Having said that, the operational side are the users. So what we have to do is convince the operators that a lot of the problems could be solved by taking a new look at simulators. Instead of going for simulators and realism, go for simulators and correct symbology and the correct relationships.

12. Smart Rather Than Fancy Simulators

MR. JEX: If you take the point that you made earlier, of having a simulator that is distinctly different from the aircraft as a hierarchical procedure trainer, could that pilot, say, be retrained to a new display system, for example, in a commercial sense? Could he be retrained in one of these advanced procedural simulators by being able to accept it as a simulator rather than as a representation of his airplane?

DR. WHITESIDE: Yes. You mean if the simulator is kept as an obvious simulator?

MR. JEX: Yes.

DR. WHITESIDE: You said advanced simulator. Advanced simulator, to me, is one with a lot of realism.

MR. JEX: No. I meant a smart simulator and not a fancy simulator.

DR. WHITESIDE: A smart simulator; I like that.

MR. JEX: But a pilot, say, who is used to dealing with knobs and dials and cross-pointers is being introduced to electronic displays, like on a Boeing 757, one of the newer things -- a very similar craft -- practices, but he's going back to the simulator to be retrained for new kinds of displays that require new procedural and perceptual --

DR. WHITESIDE: Yes.

MR. JEX: Could a pilot accept a less than perfectly realistic simulator for that purpose?

DR. WHITESIDE: I would have thought so, absolutely, because it's procedural training. It's new perception of information presented in a different way on a CRT which is, maybe, voice activated when you call out height or whatever, and the display comes up. So you could certainly teach the procedures of that interaction with the new equipment, with the new instrumented environment.

12.1 Experts and Novices

MR. JEX: Whereas a simulator with out-of-phase rough air might not be acceptable to an experienced pilot because he knows that's not what he does when he copes with rough air. It might be acceptable to a student or engineer because they don't know any better.

13. Fixing Existing Trainers - Train Procedures

DR. DUNLAP: That's another aspect that we've got to consider, and that is that I think a lot of the simulators are already in place, and so to simply say we've got to redo is maybe not the right answer because we're supposed to fix the problem in the equipment that exists.

MR. JEX: You've raised an interesting point. If you consider existing simulators, such as the ones that I'm familiar with at Williams Air Force Base, very elegant, fancy simulators, that have a number of problems in the generation of both visual scenes and motion cues, particularly with their temporal and phase distortions, what does one do in the light of your theory, your approach? What might one do to make better use of these facilities either in the procedural sense or to use them for that which they're good for? We've heard, for example, stories of how at certain of these simulators, to get the most use of them, they turn off the motion base. So here's a multimillion dollar simulator with a five million dollar motion base turned off.

DR. WHITESIDE: That's almost a justification of what I'm talking about. The fact that the users are prepared to switch off the motion so they can get on with the procedural stuff.

MR. JEX: But from your point of view, would there be a way of more effectively using the motion and visual systems that exist? What guidance would your approach give to the better use of the existing facility?

DR. WHITESIDE: My gut feeling on that would be that the existing facilities are used as they are at present -- that goes on unchanged -- but, in addition, you start developing and producing the smarter, simpler simulators, so you keep the very sophisticated ones for special requirements where you really want to find relationships of eye height and viewing and so forth in a handling situation.

MR. JEX: In other words, focus its use on those areas that amount to the procedural behavioral training, without these horrible mismatches?

DR. WHITESIDE: Yes, and possibly using it in general human factors in the broadest sense. Keep the present sophisticated simulators for general human factors or occasionally testing out some new pieces of equipment.

I want to make a point here. Again, this is just an idea. The next step, really, is to actually go through the literature and find out what there is relevant which can back up or refute these suggestions that have been put forward here. I'm quite certain in my own mind that there's a lot of back up for everything I've put in there.

DR. KENNEDY: The literature on transfer of training is the best literature to support your position.

DR. WHITESIDE: Yes.

14. Realism, Fidelity and Conflict

DR. KENNEDY: In experimental studies of transfer of training or of performance, if a simulator is flyable, if you have enough visual so that you can control your aircraft, this amount of reliable variance-accounted-for by all of the fancy features, whether they be luminance, resolution, field of view, is small. If you have a blank screen, of course, it would account for a whole lot more variance because you couldn't see anything. Therefore, from the conflict theory, it might be argued that if I increase the realism and fidelity, I may narrow the tolerance of what can be out of whack. If you could authentically increase the environment visually, inertially, and all the other ways, the narrower your tolerances of what the organism will accept before sickness.

DR. WHITESIDE: I'm not quite sure that I have got the drift, exactly. Let me try to answer what I think your question is. If you're going to use highly realistic cues there is the possibility that you might be putting a mismatch into the CBM, which could be confused with the real thing, and putting thereby some negative transfer, unconsciously, of training into a live situation. I'm saying unless it's really first-rate it might be better to think, well, we will not play at that game because we might unknowingly put in some element and copy some element which is not real, that we haven't spotted, that may lead somebody, somewhere, to transfer to the real situation and lose control of an aircraft or make a fatal error.

MR. JEX: For example, learn dependence on a wrong cue in some sense. It's notorious in moving base simulators that have sound effects associated with their leg motions, hydraulic noises, that can often be used as cues. For example, rate cues, when those are cues available from the visual environment and wrong cues are available from the motion environment because they're distorted, but the right cues are available from the sound effects, so that the pilots learn to use the sound cues to regulate their system. So that's an example of where an attempt to be realistic might, in fact, give the wrong cue.

DR. WHITESIDE: Maybe to summarize that particular aspect, my feeling is that if we use highly sophisticated simulations, which goes for realism, then there's a hazard that we may not quite achieve it in some way which would result in a wrong transfer -- in a negative transfer -- a transfer, rather, to the live situation. So to avoid that problem, and also to eliminate the subsequent associated problems of nausea and motion sickness and so forth, go instead for a much more simplified presentation which concentrates on playing at the thing, which concentrates on pretending. This is not real, this is pretending. This is symbolic. But as long as one can introduce into that symbology, really, very sophisticated principles which insure that the correct relationship and changes are taking place at the right time and in the right direction, but they can be symbolic, so you can transfer that as a box of procedure or sensory motor interaction to the right situation.

CHAPTER II

Discussion with Mr. Henry Jex
September 23, 1985 - Afternoon Session

1. Introduction - A Comprehensive Dynamic System Model for Motion/Space Sickness

MR. JEX: I'm Henry Jex. I'm the principal research engineer at Systems Technology, Incorporated, in Hawthorne, California, which does research and development in the area of manned machine dynamics and control, particularly in regard to aircraft, automobiles, submarines, spacecraft, dirigibles, etc.

Our company's emphasis is on understanding the dynamic properties of vehicles of all types, and then about one-third of the company's efforts goes into the field of handling qualities and simulation.

Over the years, it's been found that the dynamic properties of vehicles require the pilot to adapt different control techniques, and he is self-aware of the difficulty of adopting one or more strategies and the degree of concentration that he has to use. Therefore, handling qualities, subjective opinions, or ratings can be interpreted in terms of the control properties of the vehicle. A rather large body of technology has been built around this, which is my main interest.

In some cases the dynamic environment interacts with those controls to produce control difficulties, notorious of which are some things called pilot induced oscillations, PIO, and in the case of cars, driver induced oscillations, DIO. Some of these have been traced to what we call bob weight effects of the limb arm system, coupling with the stick or steering wheel of the car, or brakes and so forth.

Now, along the way we got interested in simulator sickness, and eventually motion sickness. Several years ago, about 1981 or so, we got a contract from the NASA Ames Research Center, under the technical cognizance of Mel Sadoff, since retired, to develop a comprehensive dynamic system model for motion/space sickness. That was the name of the project. It was to bring this dynamic point of view to this field, which is being investigated intensively because of the space sickness problem.

The theory I bring to this meeting reflects the work done predominantly in that period from 1980 to 1983, and some work since, and then several incidental things we have done in our own driving simulators.

STI, because of its nature, has done much off-site research at other facilities, such as those at NASA Ames, Wright Field, various places for the Navy and the Army at Fort Rucker. So most of our facility experience is not with our own facilities, it's a moving base facility, but with other sites. Whereas, on the other hand, of the very simple visual simulators of the type that Dr. Whiteside was talking about earlier, we have two or three of those for driving and flying simulators, that extract the essential information in the scene and cartoon it with calligraphically drawn computer-generated imagery, CGI.

So these CGI displays have been used a lot in our lab, and we have what we call a poor man's display for driving simulation. That's in the ten to fifty grand range instead of the one to five hundred thousand dollar range. It's a black and white line drawn CRT, but it's updated 100 times a second instead of ten times a second.

The experience with that, and the interactions of the driver with it and the effects of having and not having motion sickness, again, bear on what I bring into this. Most of our experience has been with what we call research simulators, which are developed to explore particular problems, not unlike the VTRS at Orlando, as distinct from training simulators, such as many of us have been talking about in earlier discussions here, which are those at Nellis Air Force Base, so I have, again, mostly experience with research simulators.

1.1 Kinetosis

MR. JEX: With that sort of preface, the effort that we did on kinetosis which is relevant, I want to summarize just some key points. First of all, our own usage of the term "kinetosis." By kinetosis, we mean the general syndrome of nauseous effects from such widespread situations as physical low frequency motions, visually moving fields with no motion, simulator sickness, post-motion vertigo, or nausea, mal d'embarcation, or a similar term, nausea, in a zero G environment, or space sickness, and heavy water infusion of the inner ear, the wearing of inverted or reversed glasses, etc. All of those produce manifestations that we think of within the general topic of kinetosis.

1.2 100 Facts

MR. JEX: We felt that any model has to be based on a set of facts that were reasonably well established. So we used much of the literature in the field, and assembled a summary report, STI Technical Report 1157-1, which I will refer to as the Kinetosis Report.

So we assembled datum, some general and qualitative, others more specific, and some physiological. Our intent was that each one of these would be clear--that is, not a lot of argument--and we left out a lot that were arguable. There resulted something like 100 that a model purported to be comprehensive should be able to explain. By fitting the models to the situation and varying the parameters of the situation, you might, for example, improve a disparate motion cue situation by changing the wash-out filter of a motion base, or by changing the visual extent of a visual system, or maybe even by changing some of the properties of the visual system.

1.3 Motion Analyzers

MR. JEX: The Russians use the term "analyzer" and I think that's the same sense in which we would use it. It's a functional system, even though it doesn't have a specific locus in the brain in several places. So we think of the parameters and describe the functions of these analyzer systems in a dynamic form, similar to what systems and dynamics and control engineers are used to working with. The problem we ran up against in kinetosis, after looking at the facts and trying to understand them, was the problem has been no one system is an optimal result or proper result of acting on the inputs. There's a lot of individual variation and a lot of idiosyncratic peculiarities, and some that are very hard to explain. Vomiting itself, as opposed to just the short term awareness of disparate motion, is an example. So some of these things have very poor, what I call cause-effect chains in our minds. I don't think they are clearly understood yet.

Our attempt was to build these models into functional blocks, establish the dynamics of the blocks and how they depend on the parameters that vary, and vary them to look at things. We've done this. We built a very elaborate biodynamic model of a man sitting in an airplane, subject to vibration motion, where you really have a quite legitimate nonlinear trend, but linearizable perturbation when you're holding a stick and being subjected to vertical vibration, for example, from rough air. Certain things happen, and it's partly governed by the linkage of your arms and posture, and partly by the impedances among the various parts of your body and how they interact. Of course, it's very complicated. The spine has many parts but you can use a lump parameter approximation and come out with some very good estimates of what happens. We've done this. Each individual has different proportions, different masses, different impedances, so you can't average across people a dynamic model, because the result doesn't look like anyone of them at all, it's just a smear. But you can fit each person, which have different modes, different frequencies, different dampings, linkages, whatever, posture, and then average the parameters. The result of the average parameter model looks like a typical person.

2. The Metacontrollers - Sickness Results When Expectations Aren't Met

MR. JEX: We were somewhat successful in tying together a number of works. Of course, the primary one is built on Brand and Reason's work on the conflict cues, and in particular, a dynamic idea that you build a CBM (conceptual behavioral model) of the motions that you expect. I use for this the so-called metacontroller activities. The metacontroller in the use of our human operator model is the monitoring system that's keeping track of things. We almost never have had to invoke it for normal tracking and handling research, because you're using the primary system, and the metacontroller is only involved with things like mental workload allocation of effort.

It's the metacontroller's activity I think that is the primary area where kinetosis develops. It's this disparateness between what the metacontroller and the concept models and handling of the various efferents and afferents does and predicts that tells you right away whether some cue is wrong.

For example, when you step on a loose step or snow, or lean against a weak railing, you catch yourself within a fraction of a second. And how do you catch yourself? Something in your metacontroller says, hey, I expected to get a solid result and I didn't get it. A flag goes down on the play and you clamp up your muscle system. The first thing is you don't do very much, or you pull back. But that happens so fast, there's no chance for a cognitive action to take place, and it's often nothing you encountered before, so it's not a neural trace situation. It's actually an expectation, albeit crude, that isn't met. This is at the core of the neural mismatch situation, too; the things that you expect aren't seen.

For example, a human sees certain extractions of his motion and then spaced by the visual analyzer, says I'm moving, or I'm stopping or I'm tilting. His graviter receptors and the strapdown systems that go along with his motion analyzer complex, if he's in the real world, say, "Hey, I'm moving," or "I'm stopping," and they've learned to integrate these various rates and accelerations to estimate the states of the system.

2.1 Kalman Estimator - A Model of the System (Like a CBM)

MR. JEX: This is learned from childhood, and updated, in the same sense that Dr. Whiteside was talking about an update of the CBM. In the modern way of thinking, that's called a Kalman estimator. A Kalman estimator, in general terms, is a model of the system that is continually updated by the action of the system. As events go on, it gets to be a better and better model, or in the case where systems are changing rapidly, it's always behind. Again, it's this sort of concept that's the modern way of thinking about it. That particular approach has been exploited by Charles Oman of M.I.T.

We've applied this principle to some other kinds of things, including tracking of quasi-predictable displays, such as periodic functions or narrow band functions, not unlike the wave motion of a ship on waves. The human operator has the ability to build an internal model of the wave motions, such that when you shut off the visual display or motion display, he can continue to put out the motion with a certain degree of fidelity.

If the motion is very narrow banded, very consistent, we say coherent, self-coherent, then the output is quite good, although it may be different in frequency. But he can do, particularly even complicated wave forms, like jiggly, jiggly, bump, bump, bump, and he'll learn to put out jiggly, jiggly, bump, bump, bump, about the fifth or sixth time through that cycle. That's an evidence of the Kalman estimator with his eyes closed. So this kind of problem has plagued human tracking research because inputs which are the same from test to test get learned in spite of looking random, and operators give inconsistent results, apparently. What they're really doing is learning the coherent input and closing down their compensatory control action and putting out feed forward control.

2.2 Adaptation and Readaptation

MR. JEX: And motion cues, the same effects operate--this is our point of view--in that if you have narrow band processes like waves and periodic phenomenon, you learn to either tune them out or to cope with them, motion wise or otherwise, and you may learn to put in all the postural bracing that goes along with sitting at your desk in a room that's oscillating at a perfectly regular frequency. That's tuned into your system. It gets almost wired-in in some electrochemical way, perhaps, with time constants ranging from one to three or four days.

Then when you get out of that room, you feel these motions because you've got to turn the system off and readapt it to the non-moving frame.

So we think that some of these carry over effects, and land sickness from coming off ships and so on, is this kind of effect. We've seen it in tracking. We've never verified it in simulators, but it would be a neat experiment and easy to do.

3. Blocks of the Model

MR. JEX: With that point of view, then the neuro-mismatch ideas are then those of this estimating system. In the kinetosis report we divide the thing into several blocks. The sensory system which we've talked about, visual, vestibular, postural, visceral and aural, or acoustic, the motion state analyzers which are the strapdown inertial measurement unit, or IMU, and the orientations and paths that it predicts, so that you can, for example, navigate through a dark room using only the strapdown inertial system to tell you where you are. You touch the light switch and you're within a few inches of the light switch, across a 20-foot distance. The neuromuscular system, which is the strategy selectors, the commands and efferents, and the neuromuscular control of the body dynamics, which involves a lot of feedback neurally, and two or three levels of pathway, including the neuromuscular tension which affects the breathing frequency. One reason the breathing frequency is very sensitive to tension or stress is that one of the generalized syndromes is tensing up, and tensing up causes the breathing frequency to increase and in effect I think the heart rate variations are primarily caused by that effect.

3.0 Strapdown Inertial Measurement Unit (Motion Analyzers)

3.1 Metacontrollers - Cue Estimation, Modeling, Comparing, Alerting

MR. JEX: The fourth system is the cue estimation and monitoring system. This is the metacontroller that does the modeling and updating, habituating, comparing, and alerting the person. This is when you make the wrong step, you sense it right away, or the physical motions are disparate with the visual motions and so forth. Then the result of that in the fifth block is the expected cue mismatch which results from one of two kinds of actions. One, you can resolve it, and in many cases, the resolving is by an illusion. The oculogravic is one. You interpret what you feel as an effect, which isn't really true. It's an illusion. The waterfall illusion is another one that fits into this general pattern of things. Your eye is extracted--a rate out of a textural motion is extracted--actually, a rate signal, and that signal persists after the rate is stopped, so all things in the field have the opposite rate built into them, and so on. Illusions, I feel, don't generally cause kinetosis. I would consider them within the kinetosis umbrella, but they're not severe. They're not sickness.

3.2 Endpoints - Resolution by Illusion

MR. JEX: If the cue mismatch is not resolved, you have short-term awareness. The train is going backward in the station; maybe it's an illusion, maybe it's not, but there's something not quite right. That, I claim, is an unresolved cue mismatch.

3.3 Endpoints - Short Term Awareness

3.4 Endpoints - Emesis (Sleep: No sickness because the metacontroller is shut down?)

MR. JEX: The thing that I have a hard time understanding is emesis, or actual, frank nausea endpoint. Some disparate, provocative cues do not not cause frank emesis and others do. An example is that Coriolis head tilting often causes frank emesis. Another case that's very puzzling is we have had subjects at the Surface Effects Ship high-speed trials at the Human Factors Research simulator, the ONR device now in New Orleans, where people were in an eight-foot cubicle for two days, sleeping and working in a cycle. The first guy would go to sleep right away in an upper bunk, the other guy would do his thing, and then they would swap. In some cases the person who was asleep would not feel sick or anything. This is in a sea state five at 80 knots, very provocative motion, in which half the subjects eventually did quit because of severe nausea problems. But they would sleep eight hours, six hours, four hours, depending on the work cycle that was picked, and they would stand up in the morning; it was less than four seconds between when the guy got out of the bunk and barfed. It was just like it had been waiting for him to turn 90 degrees or something. Those kinds of things are, I feel, in the last block of mechanism, endpoint mechanism, and are not well understood.

DR. GUEDRY: I was thinking about this particular thing you're commenting on. I was just wondering, the old swing studies go back to World War II and right after, and some of them before, where position made a considerable difference; where, in a supine position, people didn't get sick nearly so easily. I was wondering if by any chance it was, I've always thought of sleep, and we did it in a rotating room, as one way you get away from it. Of course, you're not moving very much. But is there any chance it was positioned, partially?

MR. JEX: I don't know the answer to that. In the sleep case, where you are supine for sleep, you've got a confounding of two effects which need to be untangled.

DR. KENNEDY: Plus, you're getting a different stimulus to the utricle.

MR. JEX: But you're also shutting down, to some extent, what I would call the metacontroller system. You can sleepwalk, for example, and not be aware, and yet stabilize an unstable system, go up and down stairs, and things that you're commonly used to doing, without being consciously aware of it. I'm not sure, but I think the metacontroller system is still monitoring, in fact, strongly so, in that case, even though you're not mentally alert. So the mental workload is very small, but I don't know whether you would get seasick under that state.

4. Duration and Timecourse (Hop Duration)

MR. JEX: The Surface Effects Ship experimental studies were among the few studies that I've been in on where really large scale motions of 20 feet at low frequencies have been used in an operational context. Bob Kennedy has been on lots of real things, but this is a fairly controlled test because the same crew works compared to a static cab and a moving cab, identically similar, everything, so it's about as closely controlled as can be done.

The seastate situation was progressively increased because partly these subjects were naive subjects. They weren't experienced seamen; whereas, in a previous test they were experienced seamen in surface effect ships. I trust the data from the experienced seamen more than these. Here, for example, is a part of the kinetosis report of some of those cases. Just to illustrate some of the points, these are low, medium, and high seastates going from roughly 0.1, 0.15, 0.2 Gs RMS. This is the time progression of the kinetosis rating scale on the Graybiel scale; one being no problem and four or five being frank nausea.

There were a variety of time course effects over a two-day period in which some of the subjects got sick right away and some of them got sick and then progressed on. But in the seastate, five more of them got sick quicker. About all you can say is that maybe by a certain time, more or less percent were sick. For levels that were not highly provocative, there is a recovery. This immediately tells an experienced modeler that such a model has to have multiplicative nonlinearity in the endpoint dynamics.

Short-term awareness is an example of another set of kind of variables, qualitative but quite ubiquitous. That is awareness of the disparate motion cue. If we compare, for example, the common display media in terms of the subtended angle of view of the eye field of view of the display that you see on home TVs, you almost never get kinetosis. As you get into bigger systems, like Cinerama and wide-screen simulators, you get this kind of short-term awareness frequently. In fact, this effect sold the original Cinerama movies. They're still used in carnivals to give people thrills but not make them sick. They found out that 150 to 180 degrees field of view is necessary, and that 12 to 20 minutes is the optimum time to give everybody, or most of the people, short-term awareness, but not have anybody barf in the theater.

DR. KENNEDY: Maybe that's how long simulator hops ought to be.

MR. JEX: There is a time course for a large population, but probably half of that population would never get sick, or take a long time.

Anecdotal information like this is a strong clue that visual subextent of complicated scenes is a powerful parameter in the short-term awareness of fixed base moving scene situations.

5. Field of View

DR. KENNEDY: Of course, as your field of view gets bigger, other things being equal, your vection is going to be more intense, as well.

MR. JEX: Our feeling is that the primary sensors involved in those effects are the parafoveal sensors, which are roughly from the limit of fovea, five to ten degrees out, to maybe 30 to 40 degrees out. In this zone the retinal elements are connected strongly in such a way as to extract streamer information about the motion through the visual field. I think this highly evolutionarily-tuned neural system is shared with many running predators and it allows you to run over a rough terrain, chasing your prey or escaping your prey, without falling down.

You can actually eliminate the central 30 degrees almost, but the streamer information I think is strongly there. It hasn't been mapped out carefully in the way I would like to see it, although Larry Young and some of the Germans (Dichgans, Brandt, etc.) have done something on this and I'm aware of that work.

Out to the periphery you have vection effects, but they're not acute. On the other hand, in the periphery, you are very sensitive to rate motions, rates of change of brightness or of position, but you're less sensitive to changes of vector streaming. So for example, looking at dots, and you were asked to estimate your speed, let's say--and Denton has done this in England with a random pattern of dots on a sort of a controlled tape projector, and he has systematically excluded various parts of the field. He finds that the speed is best emphasized in the 20 to 40 degrees region.

To wrap up this basic point of view, that the cue conflict, I think, does give the right sort of direction to what might be done in simulators.

6. The Possibility of Focal/Ambient Conflict and Other Visual-Visual Conflicts

DR. KENNEDY: If you accept the focal ambient distinction of visual information processing, could you have a conflict between the focal and the ambient systems that could result in a conflict that would make you sick? Ignore the vestibular system for the time being. For example, there are binocular cues to depth, there are monocular cues to depth, so that the many cues to depth are possibly going to be in conflict with some of the motions that you perceive in the retina. I can see how you can have one or two bits of information in a simulator that tell you where you're going, retinally, being in opposition to others in the retina. I wonder whether that kind of conflict can make you sick or can create some of the symptoms that go by the name sim sick.

MR. JEX: I don't know the answer, exactly. I think that you are aware of it, because the windshield work shows that people are aware of distorted visual scenes, where it is differently distorted in different parts of the scene. The expansion that's correct in the center gets progressively incorrect as you go out to the bent part of the windshield, for example, and people were aware of that. But I think that you don't get sick as much as reject it, as like a cartoon world. Like if a fence post strobe on a CGI, you no longer can use them for streamer information. They may, in fact, strobe backwards, so they're just rejected. What the body does is detune those that are no longer usable for control.

DR. KENNEDY: Short-term awareness is not necessarily, even if protracted, ultimately ever going to make you vomit.

MR. JEX: I have to agree.

MR. KENNEDY: I'm not sure that vomit is where we ought to be going with simulator sickness.

MR. JEX: I'll agree with you.

6.1 Distortions at Tustin

DR. KENNEDY: We need to, I think, look for examples of where there are distortions, like windscreens, some of the things that Kevin Berbaum noticed in the simulator at Tustin, where the edges are not directly butted. Also, the displays have different, we think, visual distances.

MR. JEX: The railroad simulator has the same problem.

DR. KENNEDY: These things may cause awareness which predisposes you to be uncomfortable and if you experience some other bad things involving motion, the entire experience may be one of illness.

DR. BERBAUM: Yes. What if you have binocular disparities that are telling you something completely different from the interposition or better yet, some dynamic cue.

MR. JEX: I allow that, if you can resolve it as an illusion you will, and maybe you'll accept it. But I don't think you would ever say an illusion makes you sick, per se. So I call that an awareness, but not necessarily a sickness, in the same sense that if you have disparate movie scenes, and we've seen this on a railroad simulator. It has three different projectors to do the track ahead and the track on each side and the signals, and there's a disparateness there. The cameras, themselves, are mounted on stabilizing mounts, but the motions were not exactly in sync, so when they put them up on the screen there is this Cinerama joint effect. You're certainly aware of it, and some people even say they get short-term awareness on that, but they don't ever get beyond that into the nausea state.

They put in peripheral sensors for awhile to give speed cues out the window, through bars of fuzzy texture. They find that the engine drivers need this for backing up and clues for speed control and fine precision. But in going down the track, it brings them, again, short-term awareness if it isn't exactly synchronized with forward speed, which wasn't always correctly done. So they are very aware of this. This is a case in point where people were definitely aware of disparate peripheral cues, if you will, but didn't make them sick.

7. The Possibility of Shutting Down Vestibular Input

DR. DUNLAP: Let's talk a little bit about your mismatch sensing device that's in the middle of your cue estimation modeling components. When it detects a mismatch, it would seem to me that it could go get some more information. I think Dr. Whiteside brought that up this morning, but it finally reaches the point where it says, I can't resolve it, and then rejects it.

MR. JEX: Or readapts the model to fit it. That's the thing. It gradually readapts the model to fit the data, if it's consistent data. Like in a random sea, it may never adapt a consistent view. It just says, 'I've got motions that don't agree,' and it may tune out, hopefully, and this is where I think there's a lot of visual variation. I agree with Dr. Whiteside 100 percent in that people differ greatly in personality on some of these physiological processes that are not optimized. Man was never evolved to handle operating ships, planes, and spacecraft, so there are no evolutionary neural nets to cope with this different reference frame.

DR. DUNLAP: But only one of the inputs can be turned off easily.

MR. JEX: No, you can tune out your emotion input and you can tune out the visual, okay; yes. Do you mean in the sense you couldn't turn off your motions--

DR. DUNLAP: But to turn off your vestibular system, I don't think--

DR. GUEDRY: You don't, but you certainly do as far as reflexes are concerned, to some degree. If you're highly aroused, your reflexes, your oculo-vestibular reflex is much stronger than if you're drowsy and you're not paying attention.

MR. JEX: Is that an indifference threshold or is that really just that the vestibular-ocular reflex has a higher threshold, so it doesn't respond as much, or is it actually detuned?

DR. GUEDRY: There's a couple of points of view on it. I guess one of them is that when you are aroused, some natural efferent suppression which keeps it at a relatively low level is taken off and now you get more information. We had a medical student that claimed he was practiced at self-hypnosis. I said, okay, I want you to show me you can relax, and whenever I give you a signal, I want you to start arithmetic. I was recording his nystagmus during this time, and his nystagmus would go away. As soon as I would press the button and I would start giving him arithmetic problems, the nystagmus would come in. I would say stop, relax and--

MR. JEX: So he could control it.

DR. GUEDRY: It came in and went out. I did it with a squirrel monkey, which simply--

MR. JEX: Conditioning him?

DR. GUEDRY: No, just letting him, they go into kind of a shock state when they're restrained, and it hasn't all been explained to them that they're going to be restrained. So they will lose nystagmus very quickly under a fairly mild stimulus, but every time you arouse them, it comes back again.

DR. DUNLAP: So in a sense, you're arguing that you could set somebody up and train them to ignore the vestibular input, probably through relaxation.

DR. GUEDRY: Possibly. I'm talking about nystagmus. Sensation and nystagmus go their own separate ways. They're not always together.

DR. BERBAUM: I would like to start off on something a little different for a few minutes. One of the really elegant things about a mathematical model or a simulation, from the point of view of answering the kinds of questions that we put up for discussion, is that it can be activated. You can observe it like you observe the behavior of experimental subjects. I would like to know what you've done along these lines.

MR. JEX: We have planned experiments, but conducted very few actual experiments. As I mentioned, this stage was the conceptual model stage and the next stage was to quantify. It accounts for many of the facts in a general way, but others it didn't work for. I have not been able to figure out why everybody, almost, gets sick in the head tilt. What is it that's so very disturbing about that; almost as disturbing as pure heave motion, with no head motion, no vestibular involvement, other than otolithic, perhaps, unless the heave motion implies some rotary things that aren't there, therefore, there's a cue disparity. That's hard to explain, so we have not been able to apply it to the simple case, with great success.

I've looked at such things as vestibular washouts. The vestibular system is like an angular rate sensor in the midrange, and it does not sense angular rate at low frequencies. The otolithic system senses down to lower frequencies, because it has tilt sensors and there's proprioceptive tilt sensors, but the tilt analyzer, if you will, goes down to DC. So there's a cue problem there in that angular cues and linear cues have a frequency below which they behave differently. That was thought to be a good idea, but it didn't work out. I do suspect there is this very basic thing on the motion analyzer, strapped down inertial things properly done, and they are very complicated to understand, and may, in fact, provide very strong disparate cues when certain things go into them wrong.

It's certainly true of zero gravity. If you've got zero G biases built into your model, and they go into the strapped down inertial system as a G vector in any strapped down sensors used as in missiles, the G vector has to be very carefully taken out as a vector acceleration before you do the integration. The same must be true of the neural nets that do the same thing in your head. When you take away the G vector bias, which gets wired in by living on the earth for a long time, and you go in space, then there are all kinds of wrong integrations that result. So a lot of the cue disparity, and Benson pointed this out many times, is a strong cue disparity.

Now, to quantify that, as I say, it's very hard to measure those signals, and that's the problem. It's very hard to measure the component signals to verify the models. You have to work with overall input-output models, and that makes life very difficult.

DR. DUNLAP: I want to use your model in reverse. I want to use your model to design the simulator that will make the maximum number of people sick, the maximum extent.

MR. JEX: Yes, you should be able to. When I say the model, it's a concept model not yet quantified. It's an immature thing. Conceptually, you should be able to say what this model tells you qualitatively, about what ought to be the most provoking things. I would say those situations will be provocative which involve strong parafoveal motions that are not accompanied by concordant physical motions and which involve discordant physical motions.

8. Predictions from the Model - Tweaking Your Simulator

8.1 Predicting Provocative Stimuli

DR. KENNEDY: If you have a simulator with problems with the motion base (washout perhaps), where do you go first in the tweaking. Do you shut the vestibular inputs off? You do if the visual vestibular are the bigger problem, or more specifically, do you believe that visual/vestibular conflicts are likely to be stronger, worse, more nauseogenic than visual/vestibular conflicts?

MR. JEX: That's an interesting question.

DR. KENNEDY: Do you want to answer it, Fred [Dr. Guedry]?

DR. GUEDRY: Yes. I think the answer is no.

MR. JEX: But in the space sickness sense--

DR. GUEDRY: Cross-coupled stimuli.

MR. JEX: Like the Coriolis.

DR. GUEDRY: Coriolis, and there are other examples. Everything that you could test about that question hasn't really been put to the test. You can dream up about a dozen stimuli that should be tested systematically.

8.2 Timing and Phasing

MR. JEX: What we find in investigating, whether you use so-called washout filters or attenuations of the signal or combinations of them, is that the best is a combination of attenuation and mild washouts. My feeling is that the reason for this is the behavior is enhanced if there is temporal agreement of the motion signals with the visual signals, because phasing is the most important thing for the human's stability of closed loop. The gains and magnitudes can be grossly off and he can compensate for that almost subconsciously, but timing and phasing are hard to cope with. They require leading and lagging and things of this sort, which are much more mental activities. We show that because workload and handling ratings are worse under those conditions.

DR. GUEDRY: You really can't hope to match gain or magnitude with a simulator.

MR. JEX: Well, you sort of can.

DR. GUEDRY: You could with a centrifuge.

MR. JEX: No, you can't match the linear Gs.

8.3 When is Inertial Motion Helpful

MR. JEX: The pilots in the dogfight learn to tune those out as control signals. In a violent dogfight, we've done some work along these lines, the pilots are aware of these motions and they're actually suppressing them in terms of discomfort, but they're not using them as motion cues. By using real world motions and various attenuations of them, you can show this. But it turns out that in a violent dogfight type of flying, where you're pursuing a target through the skies, you don't need and you don't want the motion cues in any flight sense. They're just a nuisance, because they act to fight you. When you want to roll quickly to follow the other guy, the rate cue of your vestibular sensor is saying hey, don't roll so fast. But when you are flying through inertial space, like rough air, then the motion cues and the visual cues are congruent, and then the motion cues can be, and in fact are, used by the human to offload the visual workload, and we've shown that by the Wright-Field experiments.

One of the earlier questions was how you could pick simulator situations that ought to use motion cues using the theory as a guide, those like transport airplanes in rough air and during landings, and coping with the carrier landing approach. Those are where the simulator motions should be given. They can be severely attenuated by factors of two or three, and still have useful transfer of training, although I haven't gotten the data to prove that.

8.4 Lags

MR. JEX: However, you do have to have agreement between the visual and motion cues. Even if the visual cues are delayed, the motions have to be made to match them because the disparity, again, in phase distortion is the worst.

DR. KENNEDY: Do you know that all Navy simulators have phase distortion?

MR. JEX: I understand they do. Any washout system does.

DR. KENNEDY: And most of the visuals lag the inertials.

MR. JEX: In some cases, yes, that's right. And the fancier the visual, often, the worse it lags, and that's wrong. You should lag the motion to match the visual, to prevent kinetosis.

8.5 How to Identify Necessary Cues - Level of Detail, Streaming, Framing - By Experiments and the Help of Artists

DR. BERBAUM: I want to ask you one of the questions that I asked Tom Whiteside this morning, and you made me promise to ask you this afternoon. As an alternative to putting in as much realism as possible, how do you identify those cues that need to be presented?

One of the big problems in landing a helicopter in the simulator is that when you get close to the ground, there are differences between what you're getting inertially and visually, because typically the visual is low detail. When you're landing a real helicopter, you're getting inertial cues and a certain level of detail, a certain density of cues that is telling you the ground is coming up below you and you are going to hit. So the experienced pilots have the most difficulty with landing because in the simulator the ground comes up more quickly than it's supposed to given the visual. Afterwards, in the real world, the ground never seems to come up because pilots adapted in the simulator to a lower amount of detail streaming before touchdown.

MR. JEX: That's a good question. We do know how and we've done it in a few cases. Much more needs to be done. What you do is you have to have a reasonably good simulator in some respects, and then systematically deny certain things. That's the basic technique. So you have a simulator that has lots of visual detail, and you take it away. You find that you can get away with very crude cartoons of the real world, provided they have some essential features. The essential features are this: They have to be appropriately moving in the foveal and parafoveal regimes. The framing with respect to that motion has to be reasonably similar to the real world. There is a very big effect of framing on these streamer effects that you learn on, and a helicopter is a good case in point.

The streamer intercepts with your framing are one of the dominant clues to your direction control of a vehicle. You can drive at high speed, without any foveal vision, over the middle 20 degrees, in fact, at high speed, down a mountain road, provided you can see the streamer intercepts with your hood window frame. If you deny that, you have a harder time driving. If you provide that, like in certain race cars with very long hoods that you can hardly see out of, you can drive just fine at 300 miles an hour without hardly seeing anything of the salt flats, but maybe a ten degree view. It's the important streamer intercepts with the hood that you're using for that clue. This part of the model holds up in that kind of test.

The way you find out what you need to do is to take away that and systematically do it. Now, there's another way. You go to the artist. You go to the Hollywood cartoon experts and find out what have they found out through years of artful insight as to what you need to simulate the effects of realism, and you find some very important clues from this. One of our consultants once said you shouldn't be talking to me, an optical expert, you should be talking to Picasso, because he can draw an animal with one line or a road with two lines, but he puts a lot of subtleties in the line and those are the things you use to get the clues out of them. They're hard to simulate, it turns out, in some cases.

For example, in the driving, you can get away with two road edges, and a rudimentary speed clue which, say, is a dashed line coming at you. A dashed line can't strobe and a dashed line can't dequantize, and a dashed line can't be erratic, because you're using it as a clue, and if it's not right, it's not good driving simulation. In the real world, posts are a very strong sense of speed cues. In a simulator they are very hard to produce because they strobe, and it's very hard to produce posts that don't have a strobing at one point or another. So here's an example where even though you can use these techniques to find out what you need, you can't necessarily simulate them easily. What you do is you avoid putting posts in driving simulators unless you have to.

What the cartoonists do is not draw posts. They draw blurs and the closer the posts get to you you will find they are just big blurs. You think there are objects there, but there are not. You saw the object out here, and as soon as it's speeded up, they just drew it as a fuzz. It was designed so that the fuzz tail from the previous frame overlapped the tail from the next frame, and your eye sees this as beautiful, smooth motion. If you looked at any individual frame of some of the early Disney things you could see where they did some beautiful work on this.

The Pole-Track Display used by Saab, Lennart Nordstrom in Sweden, is a perfect example. Lennart Nordstrom invented a Pole-Track Display, which is just the poles and no cross members of the U-shaped channel of the highway in the stop display. Now, the middle of the view field is clean. You get very good information from the poles streaming by, and you can fly very accurately under these conditions, provided it's fast enough that the poles don't strobe.

Since then, they've gone to the Pole-Track Display where the poles are fixed ahead of you, and you still, again, even though they're not streaming now, it turns out that they're easy to generate, but you get a lot of attitude and other information out of this. You can fly very accurately from this very crude display. There's no rich texture, but you can fly, and you get the right behavior.

9. Adaptation and Delaying Sickness

DR. BERBAUM: Let's talk a little bit about adaptation because it seems to me that your model is well laid out to address this issue. You have some components in there that could mimick the behavior of the adapting human.

MR. JEX: Yes. We were going to do this at one point. We did work years ago on tracking quasi-predictable displays, and we found out, you build a world model of the quasi-predictable signal, and you can put it out, and you go from compensatory, or error correcting mode of behavior, to a predictive mode, and you can almost close your eyes and put out the signal. Even when the signal is a narrow band, you can put out the next few cycles. It turns out that the character of what you put out is consistent with a Kalman type model, that says when you have a narrow band process you generate a frequency generator, and when you have a wider band, you statistically generate the average frequency and the average amplitude. So there's evidence that humans do build these kinds of models. I have not tested that for the motion cue situation, but it could well be done.

Now, those models, it turns out, take longer to build with the more variable the input is. You have to average over so many cycles to see the properties, so it takes a long time for them to build themselves. And if you turn off the input, it takes them a long time to extinguish themselves.

The thing we can explain with a model right now is when you have long aftereffects. In your [Guedry] data, you noticed that some of the people didn't get motion sick while the stimulus was on, but they did a half hour later. That kind of thing is much harder to understand.

DR. GUEDRY: That just happens occasionally, though.

MR. JEX: It's a rare thing. The mechanism still has to be found.

DR. KENNEDY: Curiously, it happens with simulators quite often.

10. Head Tilts and Emesis

MR. JEX: Another thing I can't understand is when you perform the head tilts in the dark, you get emesis very quickly. Why is that so very stressing?

DR. GUEDRY: It seems to me that that is the ultimate, almost, in the sensory conflict. I think that one phenomenon led more people to think about conflict than almost anything else, because what's happening is that, say, you tilt your head this way, the canals are signaling that your head has gone one way, and the otolith is signaling that it's going another way. They're starting to refer to the experience with circular vection in the roll plane as *paradoxical*. Well, you have the same thing, paradoxical motion with a cross-coupled stimulus. Your velocity sensation is definitely not in keeping with our angular displacement sensation. You will have a strong feeling, say, of diving but not getting anywhere, or not getting as far as you should for the velocity that you're experiencing. The otolith is signaling that your skull is going one way, the canal is signaling your skull is going another way, and the brain is trying to figure out how to keep the skull together.

11. The Possibility of a Delay Mechanism in the Emesis Path

DR. DUNLAP: How about a delay mechanism? How can you get the stimulation going on, and then sometime later feel the effect? Here's a possibility: A system that goes into oscillation, that can build up and get out of control. Your oscillation could be turning down the gain, so you turn off the problem, which would solve it momentarily, but the problem is still there. You're just shutting it off. So you then turn around and try to look for some more information, more input. What is it that's causing this thing to go wrong? That tells you if it's too bad, turn it off again.

MR. JEX: Just from a functional model, not a physiologically correct model, remember, I said you have to have a multiple cue of nonlinearity to have a diversion of this type, where small inputs don't go divergent, but large inputs do. You said there was negative feedback for small inputs and positive feedback for large inputs. There are some physiological systems which could be invoked to do that. What happens is that if the stimulus is either very long or goes enough beyond a point that the integral of its positive and negative feedback ends up being net positive. It's a dynamic process, so it's not easy to understand intuitively--but it can diverge. And once it goes past a certain point, there's no return. No matter what you do, the integral can't be made negative. Just turning off input won't do it. It's now on it's way, diverging, and once it gets to that point, a lot of the emesis path, what I call sickness path, I think is characterized by that. I even did some computer runs on it just to show that this kind of phenomenon exists, but I made no attempt to match it in data or to see what the parameters would be, or even where it would fit.

12. The Best Visual Cues for Inducing Sickness (the Parafovea)

DR. KENNEDY: If we had stripes on the dome in the Navy's research simulators (VTRS), what displacement and what frequency would you use to produce sickness? Would you use 0.2 and 16 feet?

MR. JEX: Say you want to rotate the room and not the guy, simulator sickness, that's a good question, because you want that which excites his parafoveal region strongly. What counts more is the contrast than it does the spatial thing. Do you want strong in the one degree of visual arc, you know, spatial frequencies. Spatial extents on the order of one to two degrees visual arc. A lot of texture cues are in that range, and they are strongly provocative.

DR. KENNEDY: If we move the stripes as if you were in a moving device, what do you think would govern the incidence of sickness? What principle--

MR. JEX: Frequency and amplitudes that correspond G changes of more than 0.1 Gs. On these washouts and all, when we had the lateral beam, we had linear as well as rotary acceleration, and we got some weird results in certain cases. All those cases that were weird were less than 0.1 G.

13. Conflict from Information Seeking

DR. WHITESIDE: My feeling about the conflict is that you can look at it fundamentally, as a situation in which the conceptual behavioral model that you have isn't matching the input, so you've got conflict. Now, this means that you've got to get some more feedback to resolve this conflict, because the difference is due to the fact that my feedback is degraded, or is somehow or another inadequate. In other words, if you look at the conflict situation as a need for feedback, then an automatic response to the conflict becomes perfectly understandable, and is the same as the perceptual deprivation syndrome. It's a restlessness. It's an interacting with the environment, trying to make something happen so as to get more feedback from the thing.

MR. JEX: What happens in a training simulator when an experienced pilot gets back in, and the motions don't agree with what he's used to seeing in his airplane. Suppose that you have tuned the simulators so that the visual responses are correctly dynamically tuned for the vehicle they're supposed to represent. But now the motions are disparate, because they either don't exist or they're wrong. How does this analysis cope with that situation?

DR. WHITESIDE: I'm not sure, but the way I'm putting it up, really, is to suggest that some situations exist in which, despite anything you do, the feedback doesn't improve the situation. In fact, by actually getting involved with the thing, the feedback makes the mismatch even greater. So if you move about in a Coriolis situation, you actually make your mismatch even greater.

14. Adaptation

DR. GUEDRY: Or the reverse lens experiments and so on, where any motion brings on a false visual signal, but what happens is, of course, the body adjusts to it, you change your reflexes and--

MR. JEX: That's what we're saying. You rebuild this model.

DR. GUEDRY: You rebuild the model.

MR. JEX: But then when you take the glasses off, it takes you some time to read that.

DR. GUEDRY: Sure.

MR. JEX: But if you have a reencounter, if you put those glasses on a week, a day, a month, or a year later, do you adapt more quickly from having formed that page in your model catalog?

DR. GUEDRY: From our stuff, we can't answer that as well as we would like to. People who came back two weeks later, three weeks later, some of them several months later, seemed to be able to move around in a room reasonably well, even though when we tested their reflexes, some of them had the oculomotor reflex back again, although we did have some where the oculomotor reflex was down, still, after a couple of months.

DR. WHITESIDE: But they coped with it better, quicker.

DR. GUEDRY: They coped with it better. No one got sick. What was it, in about two hours--

MR. JEX: Exactly.

DR. GUEDRY: So that part of the response returned, but they were coping with it without having any big problem.

DR. KENNEDY: I still have suppressed function in counterclockwise rotation, even though I haven't done anything in 20 years.

DR. GUEDRY: In our studies when they came back, we measured their VOR with a measured head movement once or twice, but we didn't measure it repeatedly. We don't know whether it dropped down very quickly to where they had been.

DR. KENNEDY: But we would predict it, certainly.

MR. JEX: That sounds like something that we ought to be alert to as investigators, to make sure that some of those measures are obtained on longitudinal studies, even accidental ones.

15. Kinematics and the Length of Simulator Sessions

DR. KENNEDY: This is an important issue for simulator sickness. There is one simulator we know about where people get sick at three different times during the syllabus. It is a location where we have more data than elsewhere, an air combat maneuvering simulator at Lemoore. If you look at the syllabus and the kinematics of the syllabus, there are high kinematics, flights three, four, five. It's a 30-syllabus operation and three, four, five, is when they first start doing air combat maneuvering, but it's mostly aviating, learning how to control the aircraft. Then they don't do any air combat maneuvering, although they still fly, but use it as a weapons trainer and a procedures trainer, and they don't do much aerobatics until the middle of their syllabus. Then the incidence goes up very high, much higher than the first time. Then there is another increase in sickness bump towards the end of training, so there are three bumps through the syllabus, which more or less go along with the amount of kinematics, for lack of a better word. What happens is that they adapt to each circumstance, and then recover.

MR. JEX: There's not a lot of transfer, as it were, to that.

DR. KENNEDY: There's no way to measure what we're talking about. I'm sure that those people, if tested right after they have just recovered, are going to have a lot of savings, but then they lose that. If we knew what those numbers were, we could tell them how long to make an exposure, and how short to make an interstimulus interval.

MR. JEX: It certainly sounds like that's a worthwhile area to work.

DR. KENNEDY: I'm worried about safety of flight.

MR. JEX: Your experience, you're telling us, is that even though they had that experience, somehow they didn't adapt in these new conditions. I would expect to see those peaks go down.

DR. KENNEDY: There seemed to be different amounts of movement that went on.

MR. JEX: Were there different kinds of movement? Like one case was mostly roll motion and another case was doing holddowns?

DR. KENNEDY: I believe if one were to look at what they were doing, you would put them into three different classes. You might be able to suppress the bumps based on how you put the training package together. If you were to stick to those motions experienced in the first bump, then it may be possible to suppress that whole curve. We could recommend adaptation as a viable approach to simulator sickness. I think this is delicate because you may be recommending that they adapt to something that you know is not what's in the airplane.

MR. JEX: I would say do this for cases where adapting to the motion is useful in flight. Don't try to adapt to those cases that are not useful, because you have to unlearn what you've learned in the simulator. Of course, it's very difficult to pull out, except for some of the recent simulators, what their real dynamics are. The experienced manufacturers never tell you what it is, because that's their stock in trade. It's buried in the operatives of the drive equation. It takes about a month for a simulator to reverse engineer their drive equations; to figure out what they really did. It turns out there may be nobody currently in the company that really knows because the guys that did it have left. In the helicopter simulators, I know this is true.

In other cases, they don't want to tell you because they've found out something that works pretty well, that's mostly heuristic, and they don't really want to tell you. In many cases, it's nonlinear, so it's not something easy to analyze.

DR. KENNEDY: And most of them have never been checked out against whether it improves performance.

MR. JEX: I've done some of that checking, and it's shown that they are way off in many cases.

16. Again - When to Include Inertial Motion

DR. BERBAUM: How do you tell when it's useful to adapt? In other words, are there any heuristics whereby you know that a maneuver in the simulator and in the plane are going to be the same, so that you know that you should work towards that adaptation?

MR. JEX: You can say from my point of view that conditions where inertial motion cues are going to be congruent in the real world case like, perhaps, nap-of-earth flying. It's useful to have motion cues that can be severely attenuated but they can't be severely phase distorted, and if the differences are on the order of 0.1 G in the phase distortion or transient part of it, that will probably be okay, too.

Now, for other cases, like doing these Immelmans and pulling down on targets, which are tremendous, there's no way you can simulate those cues. In fact, the pilots learn to suppress the G cues in that case, and they are operating primarily visually. In fact, what you want to do, I believe, is take away the simulator G cues, in that case. They're wrong in the first place. In the second place, you're trying to teach the pilot to suppress them, so let him focus on the visual cues and that's a better training principle.

DR. GUEDRY: In some of those maneuvers, there's no way you're going to get a motion based simulator that's going to do that.

MR. JEX: So you don't try.

DR. GUEDRY: You have to do it visually.

MR. JEX: Where you can exactly simulate the cues, in a case where they're very important and where refined visual cues are important is in air-to-air refueling or formation flying. In air-to-air refueling, you need to use every cue you've got. It's an extremely tight controlled loop. The least little thing can throw you off. Motion of ten feet is all the motion you're talking about in the whole task, and ten feet can kill your airplane. So there's the importance of being precise. The cues you have, if you try and simulate them, they're often not easy. Formation flight, you look at things like the level of the other guy's cockpit with respect to your cockpit. Try to simulate that sometime. It's very difficult to do that. In simulation you could actually, physically, represent the entire space of the task correctly.

17. CBMs, Metacontrollers and the Role of Pattern Recognition

DR. BERBAUM: I have a question that has to do with the cognitive behavioral models we talked about this morning. Can you maintain a lot of CBMs at the same time so that you might have one for each aircraft that you know how to fly?

MR. JEX: Yes. I think Tom Whiteside and I would agree on this. You build a concept model, a world model, a metacontroller model, different names for the same entity. If one is a small tweak from the other, you will take one and adapt it. If it's building a new one, you will build it, but you will build it quicker. I think most of us would agree that the more of these you build, the more situations you're able to cope with that you haven't encountered before. So yes, one reason military test pilots jump in and fly simulators and other airplanes easily is because they have this ensemble of things to draw upon, and then you adapt the one that seems to work the best.

DR. WHITESIDE: I would like to suggest that while this is a convenient way to talk about conceptual behavioral models for one aircraft or another, probably a more realistic way of expressing it would be to consider the overall input as a large data base from which you select various subsets, according to whatever is required. So you've got your broad data base of flying, and you select subset 747 or subset--

MR. JEX: Big airplane subsets, and then tweak it for the 747. It's like going to a catalog--

DR. WHITESIDE: Yes, but no matter what subset you've got, when you go in a simulator, there is no subset that you can pull out that will match what you're getting there, exactly. Do you see what I mean?

DR. BERBAUM: Yes. You seem to be saying with conceptual behavioral models, that what happens that produces sickness is that you recognize one of these stored entities that somehow doesn't fit, in some small respect.

DR. WHITESIDE: Yes. So your conceptual behavioral model, your CBM is, in fact, a subset from your data base. It's a subset that has a certain structure and certain pattern and you compare that with the behavioral model you're getting from the actual environment you're handling. If they don't match, that's a conflict situation, and if they do match, you're happy. It may not be actually cognitive. If may be something you're not even aware of.

MR. JEX: If it doesn't match in some respects, like the motion cues are incongruent with what you see, there is probably some things that you can tweak to make them match and accept, and other things which, no matter what you do, you can't easily tweak. The head tilt is an example, where the motions are so disparate that no arrangement that you can easily make in that model is going to explain those effects. In nonlinear systems, it's possible that no matter what you do, getting from here, you can't get to the fact that you require a totally different set of inputs to be accounted for. You need to start a new model, certainly the first time. Now, the next time you now have a model that allows that particular nonlinearity in its adjustments, you can a little easier.

DR. GUEDRY: Bob Kennedy said there isn't any data on a lot of these things that you're suggesting. One of the reasons is you're not going to find too many people that are going to be willing to have all of these tricks played on them time-after-time-after-time, and the chances of getting that kind of information is really not too easy to do.

MR. JEX: I have a hunch it just hasn't been gone after. You have test pilots that have gone after similar things, and they do it time-after-time and you know them because you hear about them.

DR. GUEDRY: But that's their occupation.

MR. JEX: You could go back and retrospectively ask people who have been in slow rotation rooms, what of that they reconditioned, and you can do this for some of these head inversion things. You could do it. It wouldn't really be that expensive.

DR. GUEDRY: If you have one of those guys go out and get killed a day or so after--

MR. JEX: I don't mean do it in flight.

DR. GUEDRY: No, as walking around.

MR. JEX: You're right. So you're saying the experiments have to be very carefully done.

DR. GUEDRY: They have to be carefully done, and it is not easy to get a lot of people who are willing to do it.

18. The Possibility of Vestibular Masking

DR. DUNLAP: I want to ask one question. This has to do with some stuff we talked about earlier, and I would like to get a general feeling of what everybody thinks about the possibility. Here, we have a simulator with very fancy gizmos under the motion, that can produce motion, can produce all of these great things, but so far, we've always talked about using the motion to try to produce a better scene, a better image. How about using that motion capability to try to mask, as we talked about earlier? Can we produce vestibular white noise through that motion platform, that would tend to wipe out the vestibular input, or confuse it so much that the head would say close that system down. Don't expect to feel anything, one way or the other, because it's like you don't get seasick if the vibrations are fast enough, right?

DR. GUEDRY: Yes. But one of the things that does happen with high frequency vibrations, particularly if it induces any kind of angular motion, is that the vestibular system now wins out over the visual system in controlling the eyes, so you won't be able to see any instruments. I don't know what happens with, say, kind of pseudo-random noise input.

DR. KENNEDY: Noise may not be the right term. What I think Bill [Dunlap] is getting at is maybe you could give information to the vestibular system, to tell it that it is not on a stable platform, but not any more information than that, just as though it is not on a stable platform. Then, would that be less disturbing than when you are trying very hard to come close to what the vestibular input should be, but you fall far short. What we seem to be doing now is providing the vestibular system strong stimuli, physically, perhaps with displacements or frequencies that are not good for it, in an attempt to replicate reality as a trainer. Then you give the visual as veridical as you can, and there is now a disparity between the visual and the vestibular, and the visual vestibular disparity is partly because you've gone to such great lengths to make the vestibular input--

DR. GUEDRY: Nonsense.

CHAPTER III

Discussions with George Crampton, Ph.D., and
Miller Reschke, Ph.D.
September 24, 1985
Morning and Afternoon Sessions

1. Cue Asyncrony (Lags) - Temporal Rearrangement, Phase Distortion, Variable Delays

DR. KENNEDY: In the Navy, for undergraduate pilot training, there are no simulators in flight training, at least none with visuals. It isn't until you get out of flight training, undergraduate pilot training, that you have an introduction to simulators. Once that happens, that's when the problem starts. For that reason, they probably won't select anyone out of aviation because he has a simulator problem. Also, the adaptations of the simulator invariably occur in a reasonably short period of time.

The problem basically is, I have a simulator that is making people sick. The implication is there's something wrong with the simulator. Therefore, this conference is designed to figure out, is it something wrong with the simulator, or is something wrong with the individual, and what do we do to fix it, either by fixing the simulator or the individual.

DR. CRAMPTON: I have two real simple questions. The first simple question is, do these pilots ever get sick in the actual aircraft?

DR. KENNEDY: The issues that we've raised for ourselves for simulator sickness are those instances where sickness does not occur in an aircraft doing the same thing. Otherwise, we call it air sickness. For instance, if a person were to become sick in a simulator doing the kind of thing that makes them sick in an airplane, we would consider that to be a case of air sickness and at least a realistic simulation. It is only those cases where sickness occurs in a simulator doing things that does not occasion sickness in the aircraft.

DR. WHITESIDE: On that same line, can you not tell whether the people who are sick in the simulator also get sick in the air, or was it the other group that gets sick in the air? I don't know that that information is yet available. Is that correct?

DR. KENNEDY: Yes. The closest we've come to having information like that is there is a positive correlation between a motion sickness history questionnaire scored according to sea sickness susceptability. There is a positive but insignificant relationship to how they do in the simulator. So it's an overall weak relationship, but it is in the predicted and expected direction.

DR. CRAMPTON: What do you mean by temporal rearrangement, phase shifts?

DR. KENNEDY: It appears in some simulators that the visual and the inertial lag, the input to the stick, or whatever on the control is initiated, that's a delay. It may be considered a bias, and is probably not different from what happens when you go into the helicopter or the aircraft because you have delays there as well. However, in the simulator, not only does it appear that you have a delay, but the delays are not coincident, so the visual may be 120 milliseconds latency and the inertial may be 190, or actually really the converse. Navy simulators are specced at 180 or less. All Navy simulators that we've looked at run out of spec.

DR. CRAMPTON: What do you mean run out of spec?

DR. KENNEDY: The latency from initiation of a control to when something happens to the visual in the simulators that are on-line, as opposed to the research simulator in Orlando, are greater than 180 milliseconds where they have been measured. I think that that's a true statement.

MR. MERKLE: Yes, it is true.

DR. KENNEDY: So the latency of a visual--just assuming now you don't have a moving base--the latency of the visual is occasioned by--Kevin can probably give you more precise info. But you take the stick, and at a 30 Hertz system you have a 17 millisecond sampling lag on the average. Then you go A to D, and that takes you another frame, if you will, of 30 milliseconds, and I have 47. Then you have to paint the picture, and that takes some time. It might take two frames to paint one picture, so that's another 30 to 60.

DR. BERBAUM: You also have to compute what the picture is supposed to look like.

DR. KENNEDY: That's right. You go into the computer and then you go paint the picture.

DR. BERBAUM: The computation is what takes the time, to get the perspective right, to get the eye point right, and so forth.

DR. KENNEDY: So in the CIG systems [Computer Image Generation Systems], typically you're talking 150 to 180 milliseconds as an irreducible minimum, given that everything is working properly. What occasionally happens is that you overload the computer because of the complexity of the scene. When this happens, you may have a double-frame. What the computer will probably do is paint the same picture twice in a row, and then you have a jump. Whether the jump is noticeable or not, I don't think anybody knows.

MR. MERKLE: We have a record of the frames jumping on a videotape in the other room where the person is doing a taxi on a helicopter pad. The scene content includes hangars, runway, and also fields. So it's a very rich content. And as a person does a rudder turn in the helicopter, you'll notice that the visual scene moves in a very staccato fashion. But when the person lifts up and does an air taxi, it does not happen.

DR. KENNEDY: Anyway, we are arguing that temporal rearrangement to the central nervous system has the same kind of contribution to conflict as spatial rearrangement. So if I have a temporal rearrangement, I can have the same kind of alteration and resultant requirement for adaptation as if I have mirrors reversing images. The temporal rearrangement can be in the form of a latency or a phase shift.

MR. JEX: The latency change, or what you call temporal rearrangement, which I think more fundamentally is a phase distortion of any type, and causes problems with the adaptation of the pilot or driver to the task. For example, he has to cope with delays that are comparable to his reaction time delays, and that's bad and hard to cope with. But it's a stability problem in the control of the vehicle as opposed to a cause of sensory conflicts. Now, this is assuming the motion cues are synced with the visual cues, or something like that, so that there's no conflict of cues, only a delay in a cue.

DR. KENNEDY: When I'm talking about simple delays, we're saying that the visual and inertial are not concordant. They are delayed, and they are delayed in different ways.

MR. JEX: I'm sorry. I came in late, so I missed your key point about distortion between the two cues.

DR. KENNEDY: But in a simulator what happens is they are not concordant. Another thing, a problem in one simulator in particular, is that visual and inertial latencies are not synchronous, and they are variable. So sometimes the asyncrony is 80 msec and sometimes it's 360 msec.

MR. MERKLE: The vision and the motion system are separate computers controlled by a synchronous main computer.

DR. KENNEDY: There is a tighter bound around the inertial than there is around the visual. The visual tends to suffer from increased computational load, depending on the magnitude of its content.

DR. RESCHKE: In the simulators where you have no inertial changes, are there incidences of sickness with a temporal visual lag?

DR. KENNEDY: We believe that the cue asynchrony in the simulator in Jacksonville is the culprit, and know of no good way to sort that out, other than to do an experiment which is currently being run at Orlando.

DR. RESCHKE: But, I mean, is it motion sickness, or is it a manual control problem?

DR. KENNEDY: I think it's motion sickness. K. U. Smith has some reports from the work he did with television delays and some of the results which came out of his research implies that there is a discomfort occasioned by seeing yourself come in a little late.

We're doing an experiment in the simulator in Orlando. It would be my prediction that it's going to be in the form of the asynchronous position which will be worse than the simple lag. But we don't have any other evidence, other than speculation.

2. Washout Systems: Simultaneous Leads and Lags, Methods of Measurement

DR. CRAMPTON: I had another question. Instead of just talking about latencies and so forth, it ought to be possible to draw bode plots showing the phase shifts, simply simulating a pilot producing yaw with rudder pedals at various frequencies, and then it would be like a bode plot showing the phase shifts as a function of frequency of yaw, comparing inertial with visual. One of the parameters would be, as you've said, the complexity of the visual target.

MR. JEX: Well, in the washout drive dynamics, it's not a simple time delay in many cases. There are leads at low frequencies and lags at high frequencies. Stage distortion is the appropriate term for all of that, but it can't be treated as a simple latency.

DR. CRAMPTON: Yes, and I was going to say that with a washout it would look like a reduction in gain.

MR. JEX: Yes. It's hard to measure the visual properties easily. What you have to have is a photocell system that reads on a solid object, and can read the motion of the solid object as a drawn object, because the latencies in the painting system are among the things that have to be included. So you can't just take the drive signals as the output. So it should and can be done, but it's not a nontrivial thing to do. The techniques have now been worked out, and I'll be glad to send you some stuff.

DR. KENNEDY: The issue of lags surfaced from our survey work, but it is very speculative. However, when it has been checked, lags were found. However, it is also expensive to check in the field. And if one is to talk about 20-30 simulators that may not always run the same way, this can be a real problem. We expect that these things are built by engineers to engineering specifications, and so on. We don't expect them to change, but it appears they do.

3. Simulator Lags and Pilot Induced Oscillation

DR. BERBAUM: George, just to bring you up on the discussion of asynchronies, one of the things that has been suggested yesterday by Hank Jex and others is that one way to get around this is simply to slave the motion-base to the visual, and thereby get rid of your asynchronies. But Hank cautioned yesterday that what that may do ultimately is give you overall lags that interact with pilot reaction times, and then you get pilot induced oscillations and other nasty kinds of difficulties.

MR. JEX: Not unlike the space shuttle computer lab. It's the same phenomena.

DR. BERBAUM: Although if those lags aren't very long, that may--

MR. JEX: Yes, this depends on the task. If you're flying a large transport on a gentle landing or on an up-and-away flight, navigation study, or fatigue, or whatever, then the lags in the scenes and all really aren't a big issue because they're, let's say, less than the dynamic reaction time involved in those tasks. And the criteria occurs that whenever the dynamic reaction time through the simulated system, including its effective delays and computations, presentations, et cetera, become more than a significant fraction of the human dynamic reaction time in the real task, then you have trouble. For example, if Delta-Tall, from these sums that Bob was talking about, come to a half of your reaction time, you can get on the knee of a curve of handling qualities difficulty. It's really mental workload in coping with the less stable system. And if it's one times that reaction time delay, then you're in trouble. And, in fact, I would question the training value of the device in that sense.

Now, the dynamic reaction time in things like fighters and automobiles is on the order of two-tenths of a second, typically. That's true of light planes landing in airports, for example. So the dynamic reaction time in a larger, more ponderous craft, such as the space shuttle is in, may be three to four-tenths of a second. So we're talking about latencies in the computing system then should not exceed something like .05 seconds to .1 seconds in the case of automobiles and fighter type simulators; but could be as much as a quarter of a second in the case of more ponderous craft without significantly ruining the value of the simulator for its intended purpose. And people are gradually realizing this. But to summarize a point made yesterday, the emphasis on scene complexity for realism, in order not to miss something that might be important, has caused computational delays to increase from all simulators to the point where their value for some of the purposes they're made for is being questioned. And Tom brought up the point that a much simpler display that extracted the essence that could be drawn on much more rapidly would be maybe a better recommended direction, one of our recommendations being to use simpler displays that are computed more rapidly.

DR. RESCHKE: A few weeks ago I was at Wright-Patterson and tried their visually coupled airborne system simulator, and the reaction time on that system was incredibly fast. We're talking just a few milliseconds. It's enough so that you don't see a disparity between a movement and a reaction. We were deliberately trying to modify visual input and change the output with the scene generation, coupled with head movements, such that, for example, a pitched forward head motion where the visual world normally comes to meet you, we were having it recede just 180 degrees out; and the same with a pitched backward motion, the visual world rushed towards you, and rolling motions left or right, instead of the room maintaining its upright orientation. It was designed to slip in the same direction as the role of movement. Most of the people who were doing this didn't have any sickness problems. There were a few that did.

MR. JEX: In what time span?

DR. RESCHKE: It took--I think we were spending 15 minutes in the simulator. Like I say, in the simulator--you're really not in a simulator; it's a helmet worn system.

MR. JEX: Part of the prophylactic space trainer?

DR. RESCHKE: Yes. I guess my main point was that the visual scene was fairly good, but even when you made it discordant, and coupled with the head movement, it wasn't terribly provocative. We were actually trying to see how many people we could make sick, and look to see if we were changing either phase or buoyancy, and that was the first thing that occurred to us when we saw the results was that the discrepancy was just too great.

MR. JEX: Was this disturbing to them, this sensory rearrangement, let's say, in the post-flight case and then the second question that's related is, is the degree of sensory discrepancy the same when you're just purely visual on the earth?

DR. RESCHKE: We don't know that it's the same as what we're creating on the earth. Chances are it won't be exactly the same. But I do know the discrepancy that they're trying to create right now, that's been reported, is not necessarily provocative. It's described as interesting. You know, isn't that interesting.

See, there are several problems here. One of them that interests me most is that a lot of times when you actually do get a visual sensory rearrangement it is not provocative. It's interesting. It's fun. For example, the first time I flew on a parabolic flight, AC-135, and experienced an inversion illusion, it wasn't disturbing at all. It was interesting to watch the visual world out there rotate upside down as you went into zero-G, and then when you would come back out, it would just turn back over. So I didn't turn over, but the visual world turned over. I thought, you know, that's fun, I like to do that. I could sit there and watch it all day.

4.1 Illusion May Be Provocative in One Case But Not Another

DR. RESCHKE: At the same time, people in prolonged zero-G who have a difficulty in orienting towards the vertical, or must maintain a vertical orientation relative to an earth vertical, get very ill if they're placed inappropriately. They can't stand on the ceiling of the mid-deck of the shuttle, for example. That is just immediately provocative. So they have to keep their feet on the ground. So it's interesting that you can have different illusions that are essentially the same kinds of things, and in one case be provocative and in other case not be.

4.2 Fast/Slow Adapters - Adaptation is the Cure

DR. RESCHKE: People who train for space flight are training on the ground, and they have a fixed vertical reference. It's because you disturb that reference in these people. And I think when they go into zero-G they get sick. I think that these people are slow learners as opposed to fast learners. The people who seem to not be disturbed by this adapt extremely rapidly. They have a very rapid learning curve in a new situation.

DR. KENNEDY: I think that we are coming to a position, just strictly dealing with the economics and what can we do about the problem--that it may be that adaptation is the best way to solve today's simulator sickness problem. People are going into simulators, they're getting sickness in simulators, and they're adapting to the sickness in the simulator. A question that we ask everyone is, is adaptation a viable option in simulator sickness. What are the dangers?

5. Experts/Novices - Tustin

DR. RESCHKE: It's been my understanding from what I've read and heard that the experienced pilots have a higher incidence of simulator sickness than the novices, and it's only because they had adapted to flight. I mean, they know what flight is like. And in the system where the lags and spatial orientations are slightly disturbed, then you have illness.

DR. KENNEDY: We know of an occasion where this may not be true. It is speculation, but I'll paint the picture:

If you watch pilots fly in the heavy-lift helo simulator at Tustin, you can tell, if you stand outside, which are the people who have very little actual helicopter experience versus those who have a lot and who are transitioning from one helicopter to another, because the nuggets are "all over the sky." The increased sickness that the new pilots have may be due to the sheer magnitude of the acceleration at some particularly bad frequency. On the other hand, the person who gets in there with a long history of exposure in helicopters who is now doing all of the flat turn, taxi, and the turning around, is getting a pseudo-coriolis. So the incidence in these two populations, even though the rates may be the same, may have different causes. So, simulator sickness is a very bothersome problem because, if you fix it for one population, you may not be fixing it for the other. So it is truly polygenic and polysymptomatic. It may be that there are certain kinds of useful past experiences which may interact with your conflict reconciliation ability and your adaptability ability.

6. Results of the Motion Sickness Survey

DR. CRAMPTON: I had a couple of fairly quick questions. When an individual has been on a simulator for quite some time, and whether they got sick or not is not material to my question, if they then turn around and fly within days, do they ever report instances of nausea?

DR. KENNEDY: We have almost no data dealing directly with what you ask. Some people have said that they had some experiences in the aircraft. These experiences suggest that some peculiarity of a simulator exposure may have placed them at risk in the aircraft.

DR. CRAMPTON: Yes, but not nausea.

DR. KENNEDY: Not nausea, so far as I know.

DR. CRAMPTON: The Navy has simulators of all kinds and they aren't exactly the same in their characteristics.

DR. KENNEDY: Even within model type.

6.1 Motion-Bases On or Off

DR. CRAMPTON: I think sometimes they use them with moving the platform and sometimes not. Doesn't the examination of sickness rates and features of these simulators give you a clue as to the important variables.

DR. KENNEDY: We had hoped that the survey would tell us exactly what you're saying. Nothing in the data runs counter to our early expectations. Wide field of view still makes a difference. Motion-base seems to interact with flight kinematics. So that helicopters with a motion-base, if anything, may produce less sickness than helicopters without a motion-base; but air combat maneuvering simulators without motion may not produce more and perhaps could produce less sickness. But there are not enough data for me to say that with confidence. The differing kinematics of the disparate syllabi may make the most difference.

6.2 Number of Hops and Adaptation

DR. KENNEDY: For example, the real problem with our survey was that we invested a good deal of effort in getting 1400 cases. We have 10 different simulators, each one of which has 30 hops. Although simulators are different, we don't have enough people in any cell to say with great confidence what's going on. We have a few repeated measure studies, following people over 10 or 15 hops. When we've done that, we've found that a very potent variable is the number of hops. Where we've found sickness rates to be high, we've looked at those hops and what happens thereafter. Not only is there adaptation, but the adaptation is large and dramatic. Although it is philosophically not a good idea to advocate adaptation as a cure for bad design, the strength of the improvement, the potency of the adaptation process is such that it looks as though two or three exposures, even for the person with great susceptibility, may be effective.

7. Predicting Sickness from History

Moreover, we could identify susceptible individuals and find out from them what it is in their histories that occasions sickness, then perhaps we could give some simple pre-training. Or persons that have some difficulties in the first hour of the simulator might want to spend an hour or so in a pre-trainer to get rid of the problem permanently.

DR. CRAMPTON: Sure. One of your questions is: (Reading) "The conflict theory implies that greater incidence of sickness will occur when there is greater conflict." And you already mentioned that if the conflict is so extreme, that is, if the disparity of inputs is so extreme, that it might not be perceived as a conflict, and therefore, less damaging. The old rotating room experiment that I did a long time ago, if I remember it--it was 1949. What happened, as I recall, is the individuals got sick when they were seated in a chair in the middle of a room that they did not know could turn. In fact, I put them in the chair and turned the chair a little bit. The people that got sick in that situation were the same ones who reported symptoms on a questionnaire. I do not believe the following observation was statistically significant. Afterwards I asked them was the room turning or the chair turning. Those who told me that it was the chair turning, they were turning, were less likely to get sick than those people that for a while thought the chair was still and the room was moving, and for which this illusion or vection dropped in and out. Now, that was not statistically significant, but if that is, in fact, the case, it might argue against the position of--let's see, what I'm saying is the individuals that tended to get sick were those that had an imperfect vection.

8. Perceptual Frames of Reference and Field Dependence (Relative to Vection)

DR. BERBAUM: In other words, they switched back and forth between the two frames of reference, self-motion and external motion.

DR. CRAMPTON: That's correct. The individuals who perceived that they were, in fact, turning, even though they were not--and you would say, well, that ought to be conflict of vestibular systems, telling them they're sitting still--but they were the safest individuals. I don't know exactly how to interpret it, but it might very well--had you asked the question in simulators as to how effective they thought the simulation was; those individuals that were very compelled by the motion cues were less inclined to get sick.

DR. DUNLAP: What's the question, again?

DR. CRAMPTON: Ask the pilots following simulation as to how realistic they found the simulation. Then see if that is related to the incidence of nausea in these machines.

DR. KENNEDY: Persons who are field independent may be more likely to get through. Barrett and Thornton did some simulator sickness studies in a car simulator several years ago, and they have shown that persons who are field dependent are more resistant, and the persons who are field independent are more susceptible. I don't know a good way to pull all of that together because the data that you have imply also that persons who are field independent may be the people who can accept the visual or external. There is not going to be a simple resolution of these data. Partly it may be that field independence is not so much what you are as how you behave. A person who is field independent may have a predisposition towards field independency, but if you asked him to behave as an independent person, he might be able to do it.

8.1 Tiptoe Pseudo Coriolis (Lackner)

DR. RESCHKE: For example, Jim Lackner has been doing a few things that I haven't seen published yet, but I think they're on their way, where he has a darkened room and allows the subject to sit in a chair, and part of the floor underneath the subject's chair is cut away, and under there is a revolving lazy Susan, and if you take their shoes off and they rest the soles of their feet lightly on a portion of the floor that's revolving in a totally dark room, in a matter of time they do, in fact, get vection. They feel as though they are rotating and the floor is stationary.

DR. KENNEDY: Do they get sick?

DR. RESCHKE: When they make head movements.

DR. KENNEDY: Is it universal?

DR. RESCHKE: I don't know. You make head movements as if you would in a SSCS test.

DR. CRAMPTON: Pseudo-coriolis.

DR. RESCHKE: In cardinal planes they get sick, and they make the head movements.

DR. KENNEDY: Has he [Lackner] written that up yet?

DR. RESCHKE: It's written up, and I saw a brief draft of it, yes.

9. Conflict Theory

DR. KENNEDY: I think the question Dr. Crampton asked hinges on how one understands the conflict, and I'm not sure that we understand it perfectly. I think the chief problem with the conflict theory is how does one quantify the conflict.

DR. RESCHKE: When you say more conflict, that more actually means two things; it means divergence, or it means more different kinds of input stimuli that are divergent. My guess is that when you talk about more conflict being more provocative in terms of divergence that that's not the case. But if you talk about more stimuli inputted to the system being more provocative, then that's probably where we're headed.

DR. KENNEDY: So you would suggest that if you have fewer stimuli in accord, they need to be within the same window, or band, or frequency range, or they need to be close together. If I have two stimuli that are giving me very similar information about locale, one of which is visual and the other one is auditory, or proprioceptive, would you argue then, if I had those two giving me similar information but not exactly concordant, that that would be a conflict? Whereas, if they were so markedly disparate as to not be close to giving me the same information, those would not qualify for conflict.

DR. RESCHKE: Yes, that's the way I would interpret it.

DR. DUNLAP: So experimentally you could have a rotating chair, and then a field around that chair which independently can be rotated, and you're saying when one is so completely opposite the other, that provides less problems than if they're a little bit out of adjustment.

DR. KENNEDY: I think that's what we mean.

DR. WHITESIDE: Is that reading in a conflict? Is that reading into conflict the decision or lack of uncertainty?

DR. RESCHKE: Well, I believe if the two stimuli are so discordant, that you simply ignore one of them and use the other as a base reference. If you have more stimuli input, proprioceptive, visual, vestibular, auditory, then you probably weigh the inputs according to which ones provide you more information as to which is the more correct decision in terms of what's happening in my world.

10. The Possibility of Vestibular Masking

DR. DUNLAP: Maybe we can talk a little bit about this thing that I suggested the other day, the possibility of using that motion component in a simulator to mask or to drown out the lack of vestibular input that may be causing the problem, sort of what I guess we'd call white vestibular noise. In other words, can we use some bumps, some jerks, and things like that to tell the person that his vestibular system isn't going to help in this situation; therefore, he's going to go completely visual, and maybe that has two effects; one, reducing the conflict, and the second, keeping him from learning the wrong thing, that if I turn the stick I should feel these things, but since I've got enough noise to turn off my vestibular system, I don't learn the wrong thing. Would you have a comment on that.

By the way, when I asked that yesterday, the immediate reaction of Fred Guedry was no, it won't work, but I couldn't find out why.

DR. CRAMPTON: Well, I think it has some merit, but also associated with the movement, of course, are the somatic cues which also might be defective. I think a problem--you had said something like if you made the simulator such that it was obviously a simulator with an anchor and so forth, supposing that the pilot, instead of sitting all suited up with his helmet and sitting in the same cockpit seat, was sitting in a kitchen chair, or something like that, completely different. In other words, he's dealing with that part associated with somatic kinesthesia and so forth, and it is so different it would be unlikely that he would learn cues of the transferred aircraft, or responses. In other words, not just give junk vibration, or bumps, or so forth, but change all of that part of the simulator that has to do with vestibular somatic input.

DR. DUNLAP: Well, if you were to do it, what would be your best guess at what would constitute vestibular white noise, little random jerks and things like that, or what? What would be your best guess of something that would mask the fact that there is no true vestibular response to this apparent changing visual field?

11. Simulator Freeze: The Possibility of Vestibular Masking, Simulation Off Signals, Smart Simulators that Avoid Freezes

DR. KENNEDY: Sometimes, George [Crampton], when you are in a descending turn, you exceed the limits of the aircraft, and what happens is it fades to black. Well, the vestibular system does not shut down the way the visual system does. It continues. You have not told the vestibular system in the same way that you tell the visual system.

DR. CRAMPTON: And you're moving the inertial platform during this?

DR. KENNEDY: You may be in a fixed-based simulator.

DR. CRAMPTON: Fixed-based, and you get the same thing?

DR. KENNEDY: You may be in a fixed-base simulator, or you may be in a moving-base simulator. As far as you're concerned, you are now in a descending banking turn. Now you've exceeded the limits of the aircraft, or you fly through a mountain, so the visual will freeze you and the inertial is not put in because you don't have any place you need to go. So you're now still flying, and you have mustered all the vestibular concomitant stimuli that the visual demands you have, so you've got those two things firing off together and in a comfortably concordant way. What we would argue is in those cases it might be better to give him a jolt to let him know that inertially, as well as visually, he needs to come down off something.

DR. WHITESIDE: Can you explain that? I don't quite follow you.

DR. KENNEDY: I'm assuming that I'm in a descending banking turn, so now I have a visual descending banking turn, and so now I have a vestibular descending banking turn, and let's assume that I was tilted by my simulator and it now has gone back to the zero position.

DR. RESCHKE: You do that at a rated change below canal threshold?

DR. KENNEDY: Let's say it isn't, but it's close. And it isn't for everybody, more for some than others.

DR. KENNEDY: Now I am straight and level.

DR. WHITESIDE: But you still would be doing your spiral dive.

DR. KENNEDY: But because I am doing this visually, I have made my vestibular system go along with my visual system, so they are now indicating somewhere in my nervous system that these things are okay. But when I exceed the limits of the aircraft, the visual will disappear, goes to black, but my inertial sensors which I have brought into alignment with my visual ought to continue to fire because I have not made them go to black in the same way. So there should be a persistence of firing of vestibular impulses that were recruited by the visual.

DR. BERBAUM: The vestibular system responsed to acceleration and deceleration, so that if you have an acceleration without any visual input, then you will perceive yourself as moving at a particular rate until you have a matching deceleration.

DR. KENNEDY: Now, one thing one could do is go and put in an inertial stimulus that would be proportional to what might have happened, and use tilt as a deceleratory index governing largely the otoliths as opposed to the canals. That, if you will, would be a faithful approach to the problem.

What Bill [Dunlap] is suggesting is why don't we just jolt them, maybe not even in the right direction, just shake them.

DR. DUNLAP: I mean, it's a mountain so give them a jolt.

DR. KENNEDY: Possibly even a G-seat where you just say okay, and an abrupt acceleration to bring you back to zero, and maybe we could even put it in at the mastoid to just go bloooop and that would make me say, okay, I've got to bring all my systems down to zero so I can get started and do something else again. Whether that would be helpful or not is the subject of this discussion. Does it have to be veridical, or as close to veridical, or could we make it similar? Or could we give them a jolt and let the jolt serve as a stimulus to turn your vestibular system's switch to the "off" position.

DR. CRAMPTON: Are these platforms usually driven hydraulically?

DR. KENNEDY: Yes.

DR. CRAMPTON: So it would be possible to put in a--

DR. KENNEDY: A shudder jolt.

DR. CRAMPTON: Or just simply a shudder like you get from warning bumps on a highway.

DR. WHITESIDE: What about the sound? Again, I often think of the model of the children playing, and them going bluuuu or hmmm (Indicating). All these noises can be very meaningful, and they're fairly effective as far as their playing situation is concerned, and maybe they might be effective in a very simple and practical way in the simulation where you're trying to avoid--

DR. KENNEDY: Give them a crash.

DR. WHITESIDE: Yes.

DR. KENNEDY: Some broken glass and--

DR. DUNLAP: I'm not sure that that wouldn't be bad.

DR. KENNEDY: Exceed the limits of the airplane and you hear a crash.

DR. DUNLAP: That's what I was saying, if you hit the mountain, let's have a jolt, instead of just turning them off and hanging in space.

DR. RESCHKE: What happens when you turn them off; do they get sick?

DR. CRAMPTON: This is disturbing to them, isn't it, if they exceed?

DR. RESCHKE: I really don't understand.

DR. KENNEDY: Harrison Schmidt, the astronaut, said that when you look through the porthole--you know, he took the cover off the hatch and noticed that the world was this way (Indicating), and it made him all discombobulated and gave him a bad feeling. Pilots who are in air combat would suddenly exceed the limits--and this now is in a simulator that doesn't move, at least this is where the reports came from, and they would be frozen in the altitude that they were when they exceeded.

DR. RESCHKE: In a fixed-based simulator?

DR. KENNEDY: This is where the report came from, but the same kind of thing happens in moving-base as well. I don't think that whether fixed or moving base is the important ingredient. The person is now in the cockpit perceiving gravity through his cord because he is physically upright, and he has a visual that is widely at odds with that, and it has a history, that is, he has come to it this way. Now he exceeds the limit of the aircraft, now it goes into freeze, and it stays there, stops, and--

DR. RESCHKE: And he still sees it?

DR. KENNEDY: And what happens is that interpretation of that visual compared to the persistent seated upright G interpretation is a bad experience for a lot of pilots.

DR. RESCHKE: So he exceeds the limits--say he's in a bank and it freezes there, he has this visual picture--

DR. KENNEDY: Pilots have tried to climb out of their cockpit and have fallen down.

DR. RESCHKE: So he's sitting upright looking at a tilted picture?

DR. KENNEDY: It is a tilted picture which has a temporal history. I mean, he didn't get there, you know, just--

DR. RESCHKE: I understand.

DR. BERBAUM: I have a really strong disagreement with the suggestion of using a vestibular endpoint like a crash. I think a bell that always indicates the simulation is at an end would be better. The fact of coriolis, pseudo-coriolis, and now pseudo-coriolis to simple tactile stimulation suggests that you have some nucleus responsible for spatial constancy, and that to do spatial constancy all these sensory modalities are getting analyzed along the same dimensions. Because you can get pseudo-coriolis from purely optical stimulation, indicates that you are analyzing the optical stimulation and the vestibular stimulation in a way that maps them onto each other. If you really wanted to correct the freeze problem by giving them the same interpretation in both visual and vestibular modes, you need to play that out completely. You bring them to rest so that they can make the same interpretation: a resting point. Just putting in bumps or crashes, that has a real interpretation in terms of what happens to the individual. I mean, a crash is a crash.

DR. DUNLAP: I see a problem with Kevin's [Berbaum] solution. Here you're in a big banking turn and you exceed the limits of the thing. Kevin would like you to fly back out, get stable, and then turn the thing off, maybe. But you can't do that for the pilot because you'd be taking his stick away from him. He would have to fly it back out level.

DR. CRAMPTON: Well, I don't think so.

DR. DUNLAP: Oh, you think the scene could just go back--

DR. CRAMPTON: Just like in the Cessna aircraft or something, you know, hands off, and you come back and fly level.

DR. RESCHKE: If this is disturbing someone, you've done nothing more than--whether or not there's a vestibular history, which there really isn't--

DR. DUNLAP: Right.

DR. RESCHKE: There's a visual history.

DR. DUNLAP: Right.

DR. RESCHKE: That ends up being in conflict with vestibular and proprioceptive input at the very end, which is essentially nothing more than Witkin's tilted room. It probably comes on faster because you have not been truly a vertical stimulus up to that point, and the simplest solution is to turn off the lights.

DR. BERBAUM: Yes, but the problem with that is that the vestibular input responds to acceleration so that if you have given an acceleration, that turns on a vestibular memory that says I'm moving at a certain rate, and you have the visual to confirm it, and those are in agreement, you turn off the visual. As when you fly into a cloud, you still have that vestibular memory tracking along saying, hey, you're still moving; you just don't see anything.

DR. RESCHKE: Well, you don't have the--

DR. CRAMPTON: Well, in the tilting room you don't have the movement.

DR. RESCHKE: That's right. If you're going at a constant rate, if you're flying at a constant rate, but not turning, not banking, not pulling up, or diving, or anything else, you have no vestibular input.

DR. BERBAUM: Right, but typically we are--

DR. RESCHKE: It's null.

DR. CRAMPTON: But he's pointing out that your perception is still moving.

DR. BERBAUM: Typically, when this happens, you're not flying straight and level, but you're doing something like this (Indicating) in which there is a history of vestibular inputs to the organism, and there is a memory that is interpolating from those inputs.

DR. RESCHKE: I think that the time constant for that is very short, that if you were to take some--

DR. WHITESIDE: Time constant for what?

DR. RESCHKE: For the vestibular memory of a movement. I think it's very, very short, so that if you, in fact, do go into a cloud at a constant rate of speed, so that now you have, in effect, a visual Ganzfeld. It's just a totally null environment. The sensation of moving, if the velocity is constant, isn't there; you have stopped moving. You are essentially stationary. And I think that's what the problem is.

DR. DUNLAP: So a ramped fade-out of some type would be--

DR. RESCHKE: What you're faced with is maintaining the perception of a constant movement with a visual stimulus, and no longer getting any kind of input, vestibular or proprioceptive.

DR. BERBAUM: So if your interpretation was correct, they shouldn't get sick.

DR. RESCHKE: Yes, because you're providing a movement--you still have visual input.

DR. BERBAUM: But they do.

DR. RESCHKE: What I'm saying is if you take it away from them, because the time constant for motion is so short, that it goes right away.

DR. BERBAUM: Yes, but what they've done in the simulators is they have, if I understand you, implemented a fade-out for the freeze condition rather than simply stopping, that is, they simply fade that out, but the people get sick. And according to your interpretation, they shouldn't.

DR. RESCHKE: I guess I have to know--do you just turn the lights off?

DR. KENNEDY: What they do is they totally fade-out the visual, that is, the visual gives them what we're seeing here, and then the visual--as they get to that point, the visual is stopped. There is no visual.

DR. RESCHKE: The visual is stopped.

DR. KENNEDY: The visual scene disappears.

DR. BERBAUM: And no more vestibular input.

DR. RESCHKE: But what do they see when the scene goes away?

DR. KENNEDY: They now have an imperfect view of the interior of their cockpit, and they have their cockpit lights.

DR. RESCHKE: Well, what's right in front of them? Is there anything tilted in front of them?

DR. KENNEDY: No.

DR. RESCHKE: A bank or a roll?

DR. KENNEDY: The visual scene for them is the interior of their cockpit. Chances are it's poorly illuminated, but enough to see the major struts, the canopy, the windows, and possibly some of the exterior appurtenances that are outside.

DR. CRAMPTON: How about the instruments; do they freeze?

DR. KENNEDY: Yes, and then they get reset. They just stop.

DR. CRAMPTON: I'm really in favor for getting the vestibular, but--

DR. KENNEDY: I'm sorry?

DR. CRAMPTON: I really think in this situation to forget the vestibular, but have a bell ring of some kind that says now it's on some sort of automatic, and the pilot just takes--

DR. KENNEDY: I really like the idea of the crash.

DR. CRAMPTON: Well, how cruel do you want to be? Just take his hands off and have the visual pattern straighten out.

DR. BERBAUM: Fade the visual out, but then give them a sensible vestibular input for deceleration to a steady state position. I wouldn't crash him whenever the simulator "freezes."

DR. KENNEDY: No, no, no. What I meant was I like the notion of when they have exceeded the limits have the machine go in their ears the sound of tinkling glass and Fibber McGee's closet. You know, just the sound effects. I like that notion.

DR. CRAMPTON: Well, if they're exceeding parameters for the aircraft, or they're flying into a mountain, that's fine; but supposing they're exceeding the parameters of the simulation? That's kind of unfair to the pilot, isn't it?

DR. KENNEDY: Do you mean for him to do it, or--

DR. CRAMPTON: To crash him because your computer on the simulation is not working fast enough.

DR. DUNLAP: Well, I think we all agree that it's wrong to leave the guy hanging up in space.

DR. RESCHKE: I still maintain that if you fly into a cloud at constant velocity, even if you are tilted relative to gravity--the velocity is constant with forward movement and acceleration is vertical, that if you have a perfect visual Ganzfeld, all motion stops, and you are no longer moving. You're either tilted if you're in a rolling condition, or if you're vertical you just don't move; you're stationary. I think that when you either go black in the thing, or leave the scene in front of them, that something is occurring that allows the memory to persist, and you've got to shut that off. Now, I have an analogue to the vestibular part of it. We do what's called a sudden stop test.

DR. WHITESIDE: Sudden stop?

DR. RESCHKE: Sudden stop, yes, where we decelerate people over and over again from 60 rpm at approximately 250 degrees per second. I mean, it's just bam. And after you do that you wait 10 seconds, I believe it is, and then we ramp up again at 200 degrees per second to 60 rpm, and then we wait for 30 seconds and then hit them again. We just do it over and over until they get sick, which generally only takes about three or four stops. The main point of that is that it leaves you with a memory. It's so provocative and such a massive overwhelming stimulus that after you get out of the chair a lot of people are really dizzy. The best cure for that is to get right back in the chair, go the opposite direction one stop, and there's no dizziness at all.

DR. DUNLAP: So you unwind.

DR. RESCHKE: There is a vestibular analogue. What I'm saying is there must be--if you have no vestibular input, a visual analogue to this, too. And that visual analogue--it could be nothing more, for example, than actually--I think you suggested tilting a person. The visual scene is tilted, and they exceed the limits of it. You don't even necessarily have to tilt them in the same direction that the visual scene is tilted.

DR. KENNEDY: I'm not sure you're saying anything differently from what Bill [Dunlap] is proposing. It's the same thing.

The question is that when something is done visually, and you are left hanging visually, a way to bring you down visually from being hung up there is to go to black. So that's what's being done. The question is is there an equivalent way to not have the vestibular system left hanging. And one way to do that would be to make a fairly veritical vestibular stimulus based on what we know the vestibular is processing. So instead of putting in a full stop with associated vestibular stimuli, we will tilt the vestibular system so that it thinks it is stopping, and we will do it perhaps proportional to, perhaps linearly proportional to, or perhaps at some transform of lineal because it may only be necessary--and the question he's asking is, how far away from the honest stimulus can you get and still give the vestibular system information that will satisfy it, that it doesn't have to pay anymore attention to it.

DR. DUNLAP: Or can you make a shake or a shudder that simply says, hey--

DR. KENNEDY: There's a study done by Jacobs & Roscoe where they had a GHT simulator that was flown by student pilots. This is a nonvisual simulator, and the pilots flew with visual instruments, or rather with instruments, and in that simulator they had motion that was either concordant with what the instruments indicated, or half the time discordant and half the time concordant. Those subjects who had random motion, that is, half the time concordant with what they were doing and half not, were no different in terms of transfer of training to the real aircraft than those who had concordant motion throughout their training regimen. Secondly, no subject from the group that had discordant motion ever reported that he had discordant motion during his exposures. This implies that, in this situation, the vestibular system may not be particularly informative to the human. Again, there's some--this is only one experiment, and so far as I know it's never been repeated, and didn't have a visual, but I think it suggests that it may be possible to feed information through the vestibular system to fool the vestibular system, and it may not be necessary to do it in an authentic way, and it may be very far from authentic. It's really a research question.

DR. BERBAUM: It seems to me though you have the basis of an experiment there, but you don't have the basis of the recommendation.

DR. RESCHKE: I've got a suggestion. I think I know how to fix it. You simply use Malcolm's artificial horizon, or something like that. When a system locks up in that condition, you just turn off all the lights and you have the heads up horizon and it comes right back to horizontal.

DR. CRAMPTON: Either do it that way or do it with visual display.

11.1 Unprovocative Endpoints and Smart Simulators

DR. RESCHKE: I'll bet you when they do that that the instruments freeze up, too. One of the things that these people are looking at constantly is an artificial horizon. Even though the lights come up, they still have that artificial horizon in front of them in that position that tells them that that's where they are. So now you have two pieces of conflict information. I'm sitting upright. The lights tell me I'm upright. I was in this position before I exceeded the limits, and there's my artificial horizon sitting right in front of me that tells me I'm still there.

DR. BERBAUM: It seems like we're coming to a heuristic that says whatever sources of information are available to the pilot, as far as his orientation in space, you have to give him an endpoint interpretation that's consistent and unprovocative.

DR. WHITESIDE: If the lights are on, he sees that he's not in the simulator. I have one instance where I, actually as a poor subject, operating a car simulator which is very realistic, and you're actually driving a little light along a moving roadway. And Bill Stewart, my boss at the time, thought he would play a trick on Tom Whiteside who was having great fun driving this. This was in a darkened room with just a screen, so it really was quite realistic. And he said, "Can you go faster, Tom?" So I pushed the pedal down, the accelerator, and the thing moved on. And as I went around the bend, damn it, there was a tree right across the road, and I slammed on the brakes. There was a burst of laughter from Bill Stewart. Within about five or ten seconds I was pale, I was nauseated, and I was sweating profusely. Now, that lasted, that visual response, lasted several hours. I had been quite happy. I had never been sick in a motor car ever. So what produced that response with me was purely visual stimuli conflict presented for a few seconds and producing a prolonged vegetative response which you can't say was conditioned because I had never been conditioned to being sick in a car.

DR. RESCHKE: Well, we're getting into different--if I understand you correctly, a different kind of approach, and that is that it may only be a second or less, but must being presented with that stimulus for that period of time is enough to do it. And nothing that you do after that is going to solve the problem.

DR. WHITESIDE: That's right.

DR. KENNEDY: That's absolutely correct.

DR. RESCHKE: What you have to do is fix it before that happens.

11.2 The Question of Realism

DR. WHITESIDE: Now, what happened--the cause with me was that I was so interested in this, and it was so realistic, I probably forgot that I was actually in a simulator momentarily, and I was enjoying driving this track thing. Really, I was enjoying it. I was enjoying seeing the visual. I wasn't thinking I was in a simulator. Well, I knew I was, but momentarily I probably forgot about it. I must have forgotten about it because otherwise I wouldn't have panicked and stepped on the brake; I would have just laughed and gone through the thing. But I panicked, so I must have been convinced momentarily that I was in a real car and forgot that it was a simulation. And that's the point I'm making, that maybe by making the simulator so good that it is convincing even for a short time, and then you're liable to get the mismatch.

DR. RESCHKE: Yes, I think that's a good idea.

DR. KENNEDY: What you're raising is a crucial issue for research and development into simulator design and usage. The major motivation for wide field of view, high fidelity, highly realistic systems, is to so capture you that you feel indeed that you are in there, so that what you do in there will be as automatic as it is in flight. Indeed, the plan is to so make the simulator like the aircraft so that when you are in the simulator you are modifying percepts, not just motor skills, but things will now look differently from the way that they did before. This objective carries with it an increased likelihood of simulator sickness.

DR. WHITESIDE: Agreed.

DR. RESCHKE: What you need is a smarter simulator, maybe not a more realistic simulator, but a smarter one with a good enough feedback that the system knows when the pilot is going to exceed the limits, and at that moment you begin shutting down before it ever reaches that point, because you can't let it come to the point where discordant information is available.

12. The Possibility of Recommending Backing Off Realism

DR. KENNEDY: Could we formulate a recommendation that, if sickness occurs, it may be better to back off from realism, fidelity, until the person can adapt to the simulator situation through other mechanisms, and then bring the realism back in, if that becomes something that you think is necessary in the simulation from the standpoint of the training. Or be willing to live with a training device that is going to inform, instruct, teach, and orient, but not necessarily modify the subject's perceptual scheme or the perception of events in the world. So perhaps it may be necessary to have a plan A, a plan B, and a plan C. All simulators are not going to be the same, and the same kind of solutions are not going to be advocated for all simulators or even parts of things in the simulators. Perhaps it may be necessary to identify the certain tasks where we think it's important that percepts be changed, and then ask can these really be done in a simulator. For example, almost everybody would agree that target acquisition is not going to be trained particularly well in a simulator, identification of targets, because the resolution and luminance of the simulator's presentation is not ever going to be good enough. That might be something that you ought to reserve for in-flight, and so we will not try to teach target acquisition in a CIG system; therefore, that's part of the syllabus that has to be gone through, and recognize we're not going to modify a percept here. If that's the case, then, say, all we need to do is make it representational and not have this commitment to authenticity and realism, making it compelling.

DR. WHITESIDE: In an emergency situation, momentarily forgetting that one was dealing with a game, or a simulation from moment to moment one is consciously aware that this is a simulation, and what causes you at one stage to think, yes, I know I'm in a simulator, and the next moment when something suddenly arises, bang, you think it's real. Why? That's an important hazard when the situation is such that the guy can momentarily forget it's a simulation and think it's for real. If he does that emotionally, then he's cooked his goose as far as the possibility--

DR. RESCHKE: But I don't think these people are having problems because they have found themselves in a real emergency situation suddenly. They've gone from a simulator to a real emergency. They find themselves in that position--I don't really know how to say this. They have gone from a stable visual condition, one that they were coping with, to one that suddenly has changed, very rapidly.

DR. KENNEDY: Let me ask the question differently. If we were now in a simulator, but we had all the lights on so that the targets that are being presented on the computer generated imagery are as bright and are as visible, the lines, the edges, all the visual information is as good as we have now, but we have the lights on so brightly that we know we are inside a large room that has a ceiling, maybe even an ocean, and all of that is still available, and little glances from time to time will allow us to see it. I believe in that situation it would be a less compelling simulation, and I think there would be less sickness.

DR. RESCHKE: That's true, because your peripheral vision is playing a big part in that.

DR. DUNLAP: I would argue the opposite, that if you're in a completely real situation and you move around, and you get zero vestibular input, you're going to get sick 100 percent of the time. And the model I would choose is a labyrinthectomy. If you take out the labyrinth, those people get out of the operation, they move around, and they get sick 100 percent of the time.

12.1 Field of View

DR. RESCHKE: Yes, but the thing that argues against that is that if you restrict the peripheral vision in this moving world that you have now, and maintain it more as a foveal input, there's really not very much problem with it. People don't tend to get sick, and they very rarely experience vection.

DR. KENNEDY: I don't think we know that well enough, Millard [Reschke]. I think that there's no question but that vection and large fields of view are very important in creating these problems. I don't believe we know well enough whether smaller fields of view might not be sufficiently conflicting with other things. So I think that a wide field of view is an important ingredient in sickness, but I don't think it's a necessary ingredient.

DR. CRAMPTON: Can a small field that's in the periphery have vection?

DR. BERBAUM: It depends on the area and the density of the contours that are represented in the area.

DR. CRAMPTON: We're talking about retinal location. We're not talking about size of the visual field. I'm posing that as a variable.

DR. RESCHKE: That may be true. I don't know. It's easier to make the visual field large than it is to block out foveal vision.

DR. BERBAUM: It seems to me that backing off from realism and fidelity may have its own hazards. The problem with trying to get close to realism and fidelity is that we don't completely understand how to do it. And I'm not sure we know completely how to get away from fidelity. Certainly, if you restrict the field of view, you're going to get rid of the vection cues, and that may be a problem from the point of view of trying to teach skills which depend upon vection, such as hover, formation, flight, et cetera. On the other hand, if you subtract out other kinds of information in favor of a simpler display which is representational rather than real, you may subtract out some clues to surfaces which may ultimately result in a spatial conflict because of the lack of good definition. So I disagree with the notion that what we need to do is to back off from realism. To an extent I think it may be helpful, applied situationally, but as a general fix I think it's a bit perilous.

DR. KENNEDY: What I was saying is there may be no general fixes. It may be that a particular scene, or element within a scenario, or operation needs to be looked at, needs to be evaluated, and you need to say, is it my objective here to use the simulator to train a procept; do I want perceptual learning to occur or not? In order to be able to say, here is where simulator sickness can be minimized by these techniques, we may have to be that elemental about the whole task. But, at the same time, we recognize that right here is where we're trying to teach something that is very important, and the simulator can be very useful, and some people are just going to get sick for this, and we don't have any way out. We don't have any explanation about how to fix this problem short of they're going to get sick, and they're going to have to go back to it, and that's just the way it is.

12.2 Again - Smart Simulators

DR. RESCHKE: What I was saying was that the specific problem that you had talked about, where you exceed the limits and people get ill, may not have anything to do with how realistic it is, but how you avoid the problem is to prevent it from happening.

DR. KENNEDY: I think that that still is a good suggestion, and that's one that can be made because in almost all cases when you end up having the person hung up visually, vestibularly, or both, in almost all cases that's going to be undesirable; therefore, to be able to predict it earlier and earlier, that's a good design proposal. That's a fix. It doesn't have anything to do with realism.

DR. RESCHKE: I think the easiest thing is to have a smarter system. You tell the people that you're going to exceed the limit, you know, you're headed in that direction, and correct it now.

DR. WHITESIDE: So avoid the emergencies?

DR. RESCHKE: I think you can still have emergencies. I think that you can still do that, but before you actually reach the critical moment where everything locks up and are presented with this conflict just like that, that you just simply don't let that occur. You stop it before then.

13. Head Movements

DR. CRAMPTON: One of the questions sent in advance of the meeting asks about the importance of head movements incidental to the movement of the simulator platform, or visual scene in the production of symptoms. The monkey data in particular is very interesting with respect to this. There are no cat data because it's extremely difficult to hold a cat's head still. They don't like it. Anyway, the story of the monkeys is an interesting one, and Reschke has done some of these experiments as well. But it has shown that if you put a monkey in a box, a plastic box in which they can see the walls and so forth, and rotate them at about 20 RPM, that there is a range of susceptibility, but you get a pretty good sickness rate if you let the animals move around. If, however, you fix the animal so his head can't move, and put him in exactly the same situation, the sickness rate drops enormously. And we have interpreted that as being in large part eliminating Coriolis-like phenomena.

Now, in this experiment that has been done by Igarashi, and they, in fact, fix the heads of these beasts and now they are oscillated in this pattern, and sickness is produced at that time if you present them a visual field--why am I describing your experiment Millard? Anyway, the notion is that if there is a phase difference between the visual field and the actual movement of the tape, not high sickness rates, but some sickness is able to be produced.

DR. RESCHKE: It was pretty high. I can't remember for certain.

DR. CRAMPTON: This, in fact, might very well indicate that the head movements, at least in these stimuli, are important to producing motion sickness, and if you fix the head, at least with the monkey, you'll have to have a visual-vestibular conflict out of phase in order to produce sickness. You virtually have to.

DR. KENNEDY: And so you would infer from this that pilots would have the same requirement?

DR. CRAMPTON: Right. Fixing the head should minimize sickness. And that the condition with fixed heads that will continue to show sickness will be this kind of phase shift between visual and inertial. And that may be one of the places where monkey experiments might apply. But I think it fits; I think it fits considerably.

DR. WHITESIDE: Johnson, of course, in Canada, this is one of his things many years ago showing that if he fixed the head people weren't sick and the aircraft could do aerobatics, and the people who were normally sick were not sick if their head was fixed to the back of the seat.

DR. CRAMPTON: Yes. The literature isn't entirely clear with that.

DR. WHITESIDE: Well, this is Walter Johnson's work I was referring to.

DR. CRAMPTON: Yes, I know.

DR. WHITESIDE: This was back in 1949 or so.

DR. CRAMPTON: Now, at Rochester a series of experiments were done with head fixed versus head free in a vertical stimulator without showing a difference, and I think there's something having to do with the type of vehicle.

DR. WHITESIDE: Probably coriolis in his case.

DR. RESCHKE: There's Thomas Brandt's work with the pseudo-coriolis things. We've also done some in our lab, but we haven't published any. You can certainly bring on symptoms very rapidly making head motions in a rotating visual surrounding.

DR. KENNEDY: I believe this is the source of the problem for helicopter pilots who have experience in helicopters which do some rotational activities, whether they be taxiing, or flying, or even moving, and they do a number of head movements incidental to the movement of the cab, and they probably adapt to the Coriolis stimuli that they are getting in the course of flying helicopters. When those people go into a simulator, I think that they have a conditioned response of opposite sign which they've got to get used to which may not be in new people.

14. Long Latency and Duration of Symptoms from Pseudo Coriolis (Fixed Base Simulation)

DR. RESCHKE: And there's an additional problem with that in that we've noticed sickness induced in those kinds of situations frequently has a long latency and slow onset, and the time constant for dissipation of symptoms after exposure sometimes is hours and hours.

DR. KENNEDY: When you say long, do you mean as opposed to sickness from--

DR. RESCHKE: Compare the coriolis situation to one where you're actually rotating.

DR. KENNEDY: Oh, you're saying pseudo-coriolis.

DR. RESCHKE: Pseudo-coriolis. That frequently people don't feel sick during the head movements.

DR. KENNEDY: If that's true, then that would explain some of these very, very long latency problems.

DR. RESCHKE: They get out of there, and maybe up to 45 minutes or an hour later it hits them, and they are literally ill for a while and frequently well into the evening.

DR. KENNEDY: But I've seen this with coriolis, also, where people were symptom-free during their period of exposure and you didn't hear from them for two days, and when you finally did discover, they said they went home and then they absolutely came apart, they felt terrible, never felt worse in their lives. There's one fellow in particular, Pete Theodorelis, who was incapacitated much later in the day, according to him, for two days, and he was one of the most symptom-free during the exposures.

DR. CRAMPTON: But I think, as Lackner has reported as well, the occurrence or continued occurrence of symptoms following optokinetic sickness is characterized by long periods of time afterwards. Individuals have reported vomiting after leaving the experimental situation by two or three hours.

DR. RESCHKE: The flip side of that is that we treated people for motion sickness in various environments, primarily saline, using real coriolis stimulus in a rotating room, where they were on the center axis of rotation and in an eyes open condition to maximize the visual conflict, and what we found was that the people really took well on began to get sick after a week or so at their desks. They would actually start getting ill, and the room would start tilting on them--

DR. DUNLAP: But they've been exposed to actual rotation?

DR. RESCHKE: Yes.

DR. WHITESIDE: Was there a time difference between the sensation of the motion to which they were exposed and the onset of the symptoms?

DR. RESCHKE: Well, we were doing it daily for several hours a day, and then they would go back to their offices. But the thing is, after they were adapted to the rotating room, it was at that time almost coincident with total adaptation--they could make as many head movements in there as they wanted to free of symptoms--that then they would go back to their offices, and in a stationary situation where they had a desk in front of them, and a head movement suddenly causes the desk to start moving, the room to tilt, and the symptoms come on like that.

DR. WHITESIDE: This is more or less after the experimental session of head movements during rotation, and a trained subject goes back to his desk, and within an hour or so he gets sick.

DR. RESCHKE: He's totally adapted to the actual rotating environment, but now there's a negative transfer to the stationary world.

DR. BERBAUM: Which occurs sometimes days later?

DR. RESCHKE: Yes.

DR. DUNLAP: So the offset of this pseudo-coriolis effect is slow relative to the offset of actual spinning and getting sick?

DR. RESCHKE: Yes. And I can speak from personal experience on that one.

DR. KENNEDY: It may be that helicopter simulators with visual on and the inertial off are likely to be the ones that have these long-term reports, and maybe those are the ones we ought to go look for, the long-term effects. They've been reported, but the reports are sketchy. But people have said, you know, on my way home I had trouble and I had to pull over to the side of the road, get out, and walk around my car.

DR. WHITESIDE: That was in Miller & Goodson. The kind of thing Millard [Reschke] talked about.

DR. KENNEDY: I think they were the ones who talked about it first. But there had been some isolated, five, six, or seven-hour ones, as I recall, almost always the helicopter, but now I think I'll go back and see if it was always with fixed-base. That would be interesting to look at. It might strike a blow for motion, and we might be back where we started this morning. In other words, the presence of a motion base may be such that it inhibits long-term effects.

15. How to Characterize Visually Depicted Motion. Has It the Same Effects as Inertial Motion?

DR. CRAMPTON: As to the question on flight maneuvers as far as being nauseogenic in the simulator, there's just no way to speak from data collected on animals with respect to that question because the stimulus for animals is so different from one species to another.

DR. KENNEDY: The thing I was looking for in that question was the item that Henry [Jex] alluded to: You can characterize a visual scene by a single frequency number. I've been unable to do it, but apparently Henry says that it is doable, at least I haven't had anyone who could help me by telling me how one did it.

DR. DUNLAP: Do it again.

DR. KENNEDY: The paradigm is if I hoist you 16 feet, 15 times a minute, I'm likely to make you sick. When that happens you have about a two-tenths of a Hertz frequency and about two-tenths of a G rms.

If I were to hoist you 16 feet in a simulator while you were going straight up and down looking at the runway, the hangars, and all the other things, all of the objects in your visual scene would be moving at different velocities depending on their distance from you. But if you could extract where the chief energy was in the same way that you can from a post that goes up and down, then maybe you could characterize the visual scene in the same way, and maybe the same relationships would hold, that is, this kind of maneuvering, going straight up and down at certain frequencies with certain displacements would be more nauseogenic than other frequencies, and those then could be avoided in simulators, either by software, or hardware, or other fixes. So one of the questions is, do you think that there is a companion visual frequency that is maximally nauseogenic for linear oscillation, and would it be the same one that was maximally nauseogenic for inertial translation? Secondly, can we do the same sort of analogy for Coriolis, let's say, or other kinds of angular where I turn you? Do the visual environments with turning have the same relationship? I have not found a good way to decompose the visual environment into a frequency description because when I go up and down all of the things that are at different visual distances move at different speeds.

DR. BERBAUM: You could approach it by asking whether the computed position of the observer relative to the simulated scene isn't the most reasonable domain to work within since all the different retinal frequencies are converted into the observer's self-motion. In other words, look at the motion post-space constancy.

DR. DUNLAP: Yes, because the computer generation is generated for a simple thing, and the hard part is putting in the perspective and making these things change at different-- they start from a simple thing.

DR. BERBAUM: Post-constancy, it's very straightforward. Then the results of visual simulation ought to be exactly the same as what you get by actually moving a person up and down.

DR. KENNEDY: Is there a way that we could characterize the visual scene or the simulation where we could say the following combinations of stimuli are likely to be bothersome based on what we know about inertial data?

DR. RESCHKE: I don't understand, I guess, about the different frequencies of the visual scene. Is it a three-dimensional picture so that a far point is moving less than a near point?

DR. KENNEDY: Yes. The motion parallax is legitimate for the design eye. It is as though your head is nailed to the cockpit. So there is no parallax as you move your head, but there is parallax for the nose of the airplane at the design eye. That's a problem with some simulators because the axis of rotation is not always right through the individual.

DR. RESCHKE: You know, if it doesn't do that perfectly, then I think that you have that conflict because the visual scene is not doing what your ear says it should do.

DR. KENNEDY: If you move your head incidental to the aircraft, you'll get a different visual experience than if you were to do that same thing, aside from the fact that it's monocular anyhow. It's a monoscopic view.

DR. RESCHKE: Then you're definitely going to have probable gain changes that will have an effect.

DR. KENNEDY: Sure. The experiment that would be worth running would be to have stripes on the wall of a dome simulator, let's say, that was 10 feet away, and to roll those stripes or lift those stripes up and down at the same displacement as you have when you were in a cab in HFR or any of the other linear oscillators which motion sickness has been produced maximally at two-tenths. If you were to move that as much as 16 or 20 feet, and you're to move that at a two-tenths of a Hertz frequency, and if you were to put a person in that situation, I'm inclined to believe that that would be very, very disruptive and disturbing, if you were in a fixed-base simulator.

DR. RESCHKE: I'm sure it would be.

DR. KENNEDY: If that's correct, then I would argue, if I had a visual scene that conveys to my brain the same kind of linear translation--but I don't know how to extract the elements of the visual scene so that I could ask the simulator to produce that for me. In an extracted way give me two-tenths of a Hertz. I could do it by saying make the cab move up 16 feet, and don't have me go anywhere, just have me go up and down 16 feet at two-tenths per Hertz. But I don't know how to extract that geometrically, and then describe what the visual scene would be as this is what we should avoid in simulators.

DR. BERBAUM: Of course, both of those situations could be post-constancy. For the situation where you have a scene present, a depiction to be interpreted, you've got specialized mechanisms giving you the perception *of self-motion. But even where* you're putting stripes on the screen and moving them up and down and there's no real scene there, you could still interpret those stripes as being at the distance of the screen. You've got some cues there for that, accommodation, vergence, and parallax of your head, so that the basis of disturbing effects experienced with your simple moving stripes could be post-constancy interpretation. If that's correct, it really simplifies the metric of projected scenery.

DR. KENNEDY: Is that an experiment worth doing?

DR. DUNLAP: Well, I think you'd have to do it in about six different ways, coming in and coming out at a frequency, and turning at a frequency.

DR. BERBAUM: There are some other complications as well, first of all, how close you are to surfaces. If you're 1,000 feet away from a surface, a 16 foot displacement is going to be nothing. I think it might be a good experiment.

DR. RESCHKE: Can't you just give somebody a joy stick and tell them to tell you with it where they think they are?

DR. KENNEDY: We could do that. Andy Irwin is collecting--do you know Andy?

DR. WHITESIDE: Yes.

DR. KENNEDY: He's doing some linear oscillation in G_x and G_y.

DR. WHITESIDE: A moving car, yes.

DR. KENNEDY: And he's getting sensitivities from lateral translation, other than lifting. He's getting threshold data that suggests that you are more sensitive to movements in X and Y than in Z, and he's got some sickness data implying that, in addition to greater sensitivity, you are also more susceptible in X and Y than Z. So in terms of doing all the experiments, it looks as though two-tenths is magic for all three planes.

16. Contagion of Motion Sickness

DR. CRAMPTON: I have a question having to do with psychological factors, and there's not much sense kicking that thing around. You probably did yesterday. Being a G.R. Wendt student I don't think much of it, but the only experiment I know of--well, there are two; one you said yesterday about the device that was at Santa Barbara, in running two people together, that the person that saw his partner get sick was likely to abort earlier; was that it?

DR. KENNEDY: Yes. Actually, the one that heard his partner get sick was statistically more likely to leave earlier than otherwise, based on the data.

DR. CRAMPTON: Do you remember that old experiment done by Barrow. He did it during World War II and was able to publish it when they unclassified this important experiment. He did it, I believe, at the University of California. It was starting up and stopping a rotating chair. And in one group of subjects they were tested coming from a waiting room and went directly to be tested and then were ushered out by some back door. The experimental group, however, got to sit there and watch a just-made-sick subject come out. And he, in fact, found an increased incidence of sickness of the subjects who viewed what had happened to those that preceded him.

DR. KENNEDY: I think that I've only heard about it once from you before, but I don't remember ever reading it.

DR. CRAMPTON: I think I have it just in one of those mimeographed reports that said restricted, and then it's crossed out and dated by some junior officer. Anyway, that and your experiments were the two that struck me as being that there may be a small but realistic effect.

DR. KENNEDY: Tom [Whiteside], you talked about some of that.

DR. WHITESIDE: Well, just for simularization, the child is afraid to go to the dentist. He's not really afraid. He's anticipating. He is expecting or anticipating. He's apprehensive. Apprehensive is probably a better word in the case of the motion sickness. Now, if one can eliminate that, one is left with a purely vegetative response. It's like somebody coming up and saying, "You're really going to get it, Buster." You know, "You're not going to tolerate this in any way, shape, or form," and naturally it increases the anxiety or the apprehension.

DR. RESCHKE: I certainly know that when my wife had morning sickness that I was just as bad as she was. It was definitely contagious. But there are also other stimuli that are associated with sickness that are also very important. I have one study unpublished that happened accidently. C-135s are covered with this plastic padding of gases, so that the airplane has a very unique smell to it. And we had an equipment rack on the airplane that we had flown for years, and it was sitting in the lab all closed up, no one had gone near it for almost a year. There were three of us there, and we opened up the side panel of that rack, and the smell rolled out, that was the padding on the airplane, and all three of us almost had instantaneous pallor. It was acute motion sickness associated with that smell.

DR. WHITESIDE: Did it last some time, the feeling of nausea that you had?

DR. RESCHKE: Yes, it really did. It was a very uncomfortable feeling, and it happened to all three of us standing there. And it wasn't until later that we confessed to each other that we felt bad when this happened.

DR. RESCHKE: You know, I really call into question the order of contagious sometimes, because I can be on the airplane and be surrounded with people throwing up, and mopping them up, washing them down, and it doesn't bother me at all, but I think the example with the morning sickness is that there's a large amount of empathy there that may have an effect, too.

DR. BERBAUM: I wouldn't be surprised if smells and tastes aren't more readily conditionable nauseogenically than other senses like sight and sound.

DR. CRAMPTON: We have evidence from a rat and two kinds of experiments with a cat that show there is a common emetic sensitivity, that is, that chemical emesis converges upon some pathway with motion produced signals. We have not yet done the experiment where we give cats subthreshold doses of an emetic drug and then see if we've increased their sensitivity to sickness. We're so sure the experiment would work we consider it to be a trivial one and other things are more interesting.

DR. KENNEDY: We tried to do that with LDs [Labrinthyne Defectives].

DR. CRAMPTON: Did you?

DR. KENNEDY: With ipecac and taking them to sea, and with apomorphine. Neither one of them worked.

DR. CRAMPTON: They both vomited effectively to the drugs before?

DR. KENNEDY: Yes.

16.1 Influenza and Other Illness Increases Motion Sickness Susceptibility

DR. CRAMPTON: So we haven't done that experiment, and it may not work, but I think certainly from our animal data the indication would be that emetic stimuli are additive.

DR. KENNEDY: So a recommendation about--

DR. CRAMPTON: Influenza and so forth.

DR. KENNEDY: --other fitness is probably worth considering.

DR. CRAMPTON: Well, I think so. I think from the data available--except I didn't know about your LD experiment.

DR. KENNEDY: I need to take that back. We had some trouble getting them sick without the morphine. We had no trouble with ipecac. But we didn't have enough subjects for worthwhile studies.

DR. CRAMPTON: It's one of those things you try out, and if it doesn't show a promise, then you find something else.

DR. KENNEDY: Yes.

17. The Possibility of Visual-Visual Conflicts

DR. CRAMPTON: Yes, I've done a wide variety of those experiments. It's addressed on several occasions, is it possible to have visual-visual conflict, for example. Quite recently we looked at this question when we were designing our monkey experiment for the shuttle. I wrote a couple of letters. I wrote one to Fred Guedry, and one to Lackner. I said somewhere, somehow, somebody said that in the conflict sickness an essential component was vestibular, and I can't find that reference. Did they say it, or can they tell me who, or indicate what the evidence is for that outstanding statement? And in due time they both wrote back very scholarly letters insisting that neither of them had said that, and pointing out that, although people generally talked that way, there was no convincing evidence, and that at least one of the components in a conflict situation had to be vestibular. Then Lackner indicated that he had gotten money to test LD subjects up there at Brandeis in an attempt to see if he can produce conflict between other inputs in well compensated subjects to see if he might make them sick. I'm pretty sure that he'll succeed.

DR. KENNEDY: Are you?

DR. CRAMPTON: It may be a very narrow set. It may be a fragile finding, but all you have to do is show it once. And, of course, there is the trouble with knowing whether they really are LD subjects.

DR. KENNEDY: And where the LD really is.

DR. CRAMPTON: Yes. Well, you folks have worked with LD subjects and I haven't. I've worked with animals without their labyrinths, and there we have a chance to check things out. I think that for a well-compensated animal or person it may not be visual-visual, but visual-postural to a range of highly contrived situations, perhaps just prism sickness might do it, if done right, or wearing prisms with a lot of motor movement.

DR. KENNEDY: Or maybe wearing prisms in a simulator.

DR. CRAMPTON: That may be another trick. I think your simulator is a beautiful way to do it. So I don't know about visual-visual alone.

DR. KENNEDY: The example that we came up with was different monocular cues to depth, set off in apposition. Ken Money mentioned an interesting experiment. He has six diopter contact lenses and six diopter regular lenses, giving him clear images, but total reversal of depth. And when he wears them he produces sickness very dramatically in himself with very few head movements.

DR. CRAMPTON: Do you mean he has plus six and minus six?

DR. KENNEDY: Yes. So he wears a regular lens with a contact lens combined. Now, if I were to translate myself through the world with those on, even if I were labyrinth defective, I'm going to have all of my extension capabilities screwed up.

DR. WHITESIDE: Well, what's he seeing?

DR. KENNEDY: Well, he's seeing objects, I guess. The way he explained it, and I don't understand well enough the optics --the way he explained it is that things have a different relation to each other which is minified or magnified.

DR. WHITESIDE: So different size objects. The objects will look different size according to which eye you look at it with; is that right?

DR. KENNEDY: No, the way I understood it, he had contact lenses on both eyes and glasses on both eyes, and it permitted everything to be in focus because he had plus six and minus six together, but the relation of them to each other was distorted in depth.

DR. WHITESIDE: Yes, well, that's really what I meant.

DR. BERBAUM: Because it occurs only with head movement, you have a confound. When you have head movements, you get into visual, vestibular, or postural conflicts as well as visual-visual.

DR. KENNEDY: But it is possible that it would be conflicting to a person with bilateral labyrinth defects, and that's really the only reason I brought it up. That could be a visual-visual conflict.

DR. CRAMPTON: Where this came up was in designing a space monkey project in which the animals would be labyrinthectomized and well compensated. Igarashi will do it, so we'll know it's done right. The idea, of course, was to show does space motion sickness require functioning labyrinths. However, is there a possibility in the shuttle that this monkey would be in a situation in which there would be another conflict not involving labyrinths, and therefore, could get sick. Then we'd have a whole bunch of people saying, "See, it's not really motion sickness," when, in fact, it still is conflict sickness within the parameters that we're talking about. So we thought this over rather carefully, not wanting to put it in so that the peer review people would get all caught up with that--we thought it was a little bit too difficult a concept. What happened is we couldn't think of a way unless we used reversing prisms on these monkeys or contrived such a situation. We tried to think is there anything to produce conflict in these beasts in their normal living in a cage, and we can't. But we have Igarashi very interested in trying to produce sickness in labyrinthectomized monkeys. That's of far more theoretical interest I think. I would say that it's possible then to have visual-visual or visual- proprioceptive sickness, and something you might like to consider as being quite possible.

18. Biofeedback, Desensitization and Support Therapy

DR. CRAMPTON: The question came up about biofeedback. I know that Mill [Reschke] here doesn't care for it at all, but I'm something of a believer in it. If the data that have been shown thus far are to be believed, I would like to see other people take a good crack at this than those in the limited club that have.

DR. KENNEDY: Well, what are the people at Brooks doing, what is Davy Jones doing?

DR. RESCHKE: Davy Jones is doing a variant of what Pat has been doing. Actually, he was doing it before Pat. I really don't know. I went and watched Jones' operation one day, and I was impressed. You know, I thought they were treating people very responsibly, and the whole program seemed to fit together very nicely. I just didn't believe it when I walked away. What I believed instead was here are a bunch of people that can get sick whenever they want to and not feel bad about it anymore. That's what I felt. I mean, they had been psychoanalyzed and psyched up to the point where they could throw up during the mission and not feel bad about throwing up. That's what *it looked like to me*. It didn't stop them from throwing up. None of these people--well, I shouldn't say none, but very few of these people were actually flying high-performance aircraft.

DR. KENNEDY: The astronaut group may have some of the same things said about them. Those are people who are willing to. Ken Money gets sick, and that's the price he pays for flying airplanes. That may be worth it.

DR. WHITESIDE: The point about throwing up and not worrying about it, I think this is really what I have in mind when I'm talking about the effect of deconditioning, so that it may not decondition the vegetative response, so they do throw up, but they're not worried about it beforehand.

I was on a mission some years ago with Long Range Patrol and Coastal Command, in those days that's what they called it, doing submarine dunking and so forth. And we were diverted onto a search pattern for some vessel that was missing because there was a force 10 blowing, and we were going down to interrogate and coming back up, and going down and coming back up, so it was really pretty nauseating. And one member after another of that crew went back to get a little vomit bag, came back, didn't bother them, and went on with the job. The skipper and every single member of that crew, but fortunately not all at the same time. But they weren't bothered about it; they just accepted it and went on with the job. And they didn't look ill afterwards, or indeed before it. They didn't look pale, and their job performance didn't suffer.

DR. DUNLAP: You mentioned biofeedback, and Jim May and Tom Dobie haven't gotten here yet, but I just analyzed their data on the question. They put people in a rotating drum with the bars, and they pickup out of about 100 subjects, those that were very, very susceptible who would feel very strong effects of sitting still and just watching bars go by. They tried Tom's desensitization approach. With that treatment the subjects got better and better. They could take more and more. And with the biofeedback there's no significant difference anywhere; it doesn't interact. I don't know what the biofeedback was, or whether it was done effectively or whatever. Those are specific things that should be addressed to Jim and Tom when they get here. But the biofeedback relative to this sort of desensitization, keep calm, don't worry about it, you can do it with a little practice, a stiff upper lip, and that sort of thing.

DR. WHITESIDE: The biofeedback is a lot more than that. It's a question of controlling some of your vegetative responses, and by monitoring the psychosomatic response, or your heart rate, and so forth, not like monitoring respiration that you have control over, but one of the ones that you don't have any control over. And by doing that, one gives the subject the ability to put himself in some relation to his respiratory patterns, or he's making use of the respiratory cardiovascular link, you know, and altering the heart rate.

DR. DUNLAP: You'd think it should work, but in this simulated simulator it really didn't work at all. It didn't help the subjects to know that there autonomic--

DR. CRAMPTON: I think it depends on the training.

DR. DUNLAP: Yes, I think that's true, too.

DR. CRAMPTON: Well, I'm still a believer in the biofeedback, but I feel that it is a necessary requirement that the criteria is vomit. Any experiment short of that I think is a waste of time and I wouldn't run it.

DR. WHITESIDE: I'm not going to talk for Tom Dobie, but I think that what was taking place from what he said was that the people were taught relaxation therapy using biofeedback, and they were then put into the stressful environment, but were not told to use the biofeedback techniques. Merely, all that happened from what he was saying was that they were taught to control vegetative responses by biofeedback, and very deliberately that was not used as a key. So it was a nonpunitive situation; whereas, the way I use it is to say very specifically, "Now you know how to do that. Go into the stressful environment, note your own feedback by putting your hand on your pulse, for example, or watching the galvanometer response, if it's a PGI, and observe how you can control this in relation to your new stressful environment." Now, that might not have been done, but you can check when he comes.

DR. DUNLAP: That's why I hesitated to talk about it because he hands me the data, and it's group A, group B, group C, and group D, and not much detail about the actual treatments they got. But I can tell you that what they call biofeedback didn't work.

DR. RESCHKE: The problem I have with it is it's important to look at who does the training, and I think if we're going to look at it as a solution to a problem, that if it is as esoteric as that, that doesn't make it a viable alternative, at least for immediate implementation.

DR. CRAMPTON: I think you ought to go out and talk to a lot of psychotherapists.

DR. RESCHKE: Well, you know, I've had the experience myself. When we were trying out the acupressure--I can't remember what point that is on the wrist--but I didn't believe that; I didn't believe it worked at all. But I went back in the lab, and they had just finished running a young woman who was very ill, and I said, "Well, I'll try it." So I took her wrist and pressed down, and I said, "Do you feel better now?" and she said, "Yes, I feel much better." And I took my hand away and said, "How about now?" and she said, "No, I feel worse again." And when I pressed again, she said, "Oh, I feel much better now." It had nothing to do with pressing, but she was feeling miserable and she liked being touched.

DR. CRAMPTON: Well, anyway, the biofeedback story still requires more work. But I think you'll have a nice chat with Dobie and see what in the world is going on. I don't regard relaxation therapy as being specific enough for this. Supportive therapy is nice for little old ladies and overage pilots, but I think--

DR. KENNEDY: Support therapy may be a very useful thing in terms of simulator sickness.

DR. CRAMPTON: Yes.

18.1 Education - A Series of Pamphlets on the Problem

DR. KENNEDY: I think a series of pamphlets describing what simulator sickness is, what we know it, and the fact that the situation is the way it is, and not everybody gets it. Ninety percent of the symptoms occur in 20 percent of the people. If you happen to be one, here is what you do until a doctor comes.

19. Sensory Conflict Theory

DR. DUNLAP: Is there any competitor by way of a theory to the sensory conflict model? There's the argument that stomach contents are held differently, and maybe that's making people sick, and I think Charles Wood wants to send a labyrinth defective in the shuttle for that reason. But I think if we're talking about on earth in a normal G field and so forth, nobody has suggested anything to me that sounds like another model.

DR. RESCHKE: I am beginning to doubt it myself as just a general explanation, but I don't know how else to phrase it. You're looking at a mismatch of information. It doesn't necessarily have to be in conflict. I think we're talking about perceptual systems. If I blindfold a person and sit him down outside where there's recently been a campfire, and I use a heat lamp to warm up one side of him and crinkle some cellophane to make it sound like a fire, and then throw in a little smell from a recent campfire, he'll believe that there's a fire. You fooled the sensory system. So you're really talking about a system approach.

DR. WHITESIDE: But there's no mismatch in your example of the campfire.

DR. DUNLAP: Under those conditions, if everything agrees, nobody gets sick, do they?

DR. RESCHKE: You may, simply because you've fooled the system. The information may have fooled the system.

DR. BERBAUM: It's not really conflict, but just that there are some stimuli that evolutionarily indicate that you're going to kill yourself, or that what you're doing is just not really a very good thing to do. Sickness is a way of telling you to stop doing that.

DR. DUNLAP: The one exception to the conflict theory I can think of is the following: If you go up and down as in a ship with lots and lots of information that that's precisely what you're doing, going up and going down, going up and going down. Perhaps you even have bars out there where you can see that you're going up and down, I believe you'll probably with enough of that still get sick. So there's no conflict.

DR. BERBAUM: You can cast that in terms of conflict though.

DR. RESCHKE: That's the thing. And you can also get sick. It depends on what your point of reference is. If you're looking here, at a close point, you better believe you're going to get sick. If you're looking ten miles at a distance, then it's probably not going to be a big problem.

DR. BERBAUM: At some particular frequencies some of the systems may get out of sync in terms of what they're indicating; neurally, they are asynchronous.

DR. DUNLAP: But it's not a conflict in perception. Let me pose it in terms of an experiment. I'll create a room that has lots and lots of bars, and lots of stimulus, so I know exactly where I am in that room, and I'll put an elevator in there and I'll go up and down, and up and down, and focus on the wall. I think that I'll still get sick even though my visual system says, Dunlap, you're going up and down. But with the sensation of going up and down, I think I'd still get sick.

DR. BERBAUM: What I'm saying though is that it could be an artifact of the neural encoding of those veridical stimuli. That's why particularly frequencies and accelerations maybe bad.

DR. WHITESIDE: There's a conflict between the visual input and the vestibular input. Vestibular input in that case is probably correct in affecting the acceleration changes. On the other hand, the accompanying ocular reflex eye movements in terms of elevator illusion are at least real eye movements, or the tendency to eye movement, which if you're looking at a distance and fixating on something, you are controlling or suppressing. These controlling movements also produce an illusion of eye movement, so the net result is you get a visual illusion which is not compatible with the true picture. What I'm saying is reinforced by the fact that if you put your subject into a plus Gs or a reduced Gs environment, and deprive him of feedback on his performance on the hand and eye coordination test, then the pointing is too high in one instance and too low in one instance. So there is some kind of mismatch taking place there.

DR. CRAMPTON: And if they're blindfolded, why do the sickness rates remain high?

DR. RESCHKE: You can say the same thing about the proprioceptive input. It's also a conflict phase-wise with vestibular input.

DR. DUNLAP: It gets a little stretched. You can think of examples that stretch the mismatch theory a little bit.

DR. WHITESIDE: So far we've been talking about visual and vestibular, but the conflict picture can be more extensive than that. I think it involves the entire perception of the ambient world.

Many years ago I had set up a special room in the dark in the middle of which was a flight trainer--the room was dark, the subject was in darkness, and we operated the controls from outside. There were headphones worn by the person with white noise so that he couldn't hear the changes and the movements of the bellows, and it started off visually. We had a light source that could give him the visual stuff, and we also could rotate the sound. And with the subject stationary, when rotating the sound, he felt unwell. Much the same way as you do with the *pseudo-coriolis things* and the moving bars. But these guys were getting symptomatology of this type with moving sound.

CHAPTER IV

Discussion with Walter S. Chambers
September 25, 1985 - Afternoon Session
September 26, 1985 - Morning and Afternoon Sessions

1. Cue Asynchrony

DR. BERBAUM: Some simulators appear to have an asynchrony between the visual and the inertial display. For example, the central computer, the platform, and the visual scene must all be integrated, but there are constraints such that the visual requires somewhat more computation time than the inertial, or vice versa. Therefore, in those places where it has been studied, the visual and inertial signals may not begin at the same time, nor end at the same time, nor move to the same place at the same rate. Moreover, if wash-out is added, the problem may be compounded. What is your opinion about these lags? Do you think that phase relationships can strongly effect a conflict which is sickness provoking?

1.1 200 msec Lag Limit

MR. CHAMBERS: Yes. There are a number of cue sync problems that have been shown to exist in a lot of simulators, and they vary in that in many cases the visual will lag the motion cue, and in other simulators it will be vice versa. In either case, if there becomes a significant difference between them there are usually complaints. Some attempts have been made in simulators to make them match up by delaying the lead-in cue. However, if you exceed a certain amount, then that's perceived as the whole system going bad, so there's a limit to what you can do. The limit is somewhere around 200 milliseconds. If you go beyond that in trying to match cues, you're destroying the entire simulation dynamics.

DR. DUNLAP: It's not in terms of sickness. It's in terms of ability to fly; is that right?

MR. CHAMBERS: Ability to fly and the willingness of the pilot to even deal with the thing anymore, because he has PIO.

DR. KENNEDY: And it becomes noticeable.

MR. CHAMBERS: It becomes very noticeable and objectionable. We're talking about reasonable maneuvers. If you make your maneuvers slow enough, you can carry the delay on out before it's noticed, but for any reasonable maneuver for a military aircraft, that would be true.

1.2 40 msec Asynchrony Limit

DR. MAY: What sort of asynchrony between the cues can they tolerate?

MR. CHAMBERS: I don't know good definitive numbers on that, but rule of thumb numbers are around 40 milliseconds between cues. If you can stay under 40 milliseconds, you're probably not going to get complaints.

DR. KENNEDY: In terms of simulators that you know, like those that went online in the last year or two, there are some that exceed those limits; is that true?

MR. CHAMBERS: The more recent ones are staying under those limits. It's the older ones in the field that are more of a problem, and most of the problem is in the computational system. The iteration rates are low on the computation system. It's not only the basic system, but it's the choice of the programmer as to how often he's going to update certain rates. We've seen situations where the motion is updated at a very low rate, and that would cause the offset between the cues. In the other cases, the aircraft position computation is updated at a lower rate than the aircraft attitude position, and this creates another kind of cue disparity.

2. Possible Guidelines for Fixing Simulators

DR. BERBAUM: Can you offer any heuristic that we might apply for selecting retroactive fixes for some of these things. For example, "yoke the visual and inertial and do not create lags of more than 200 milliseconds, otherwise delete the longer of the two." I think you mentioned in some earlier discussions about the amplitude of the inertial displacement that you're able to use, defining -- trying to define -- good motion versus bad motion. Can you speak to that?

2.1 Inertial Cue Amplitude

MR. CHAMBERS: Yes. I think there's a problem with the cue being enough to make a difference. Just like there can be too much time lag, there can be inadequate amplitude to make any effect. Not that there's a lot of documentation to support these particular numbers. If the motion cue maybe represents maybe less than 20 percent of what the aircraft is going to provide in a similar maneuver, it may be of no value to the pilot to be present at all, and if it's late, it will only be harmful. We found this in some helicopter tests where we could find no performance effect in helicopter hover, that is, ability to hold a precision position, when the motion cues were in below 25 percent. When we cranked them up to near 100 percent of what the aircraft provided in that hover position, it had a significant improvement in its performance, compared with no motion.

So if you don't have much of a motion cue to start with, you're probably better off just to turn it off if it's disturbing, in that it's got some cue disparity with something else in it.

DR. MAY: Can we move over to simulator sickness? What you're talking about is the performance of a simulator and how well people can learn to fly in the real world by practicing in the simulator. But what about simulator sickness? Do you think that if we buy this conflict theory, if the image is moving, the person should have conflict? What if you move the person somewhat, maybe 20 percent of what the aircraft would actually do, does that reduce simulator sickness or increase it or what?

MR. CHAMBERS: That side of it hasn't been tested because there haven't been many, if you will, simulator sickness tests of a comparative nature. Most of the tests have been performance tests. Those are things that need to be done.

2.2 Variable Asynchrony

MR. CHAMBERS: In addition to cue disparity, some simulators have a time lag inconsistency, in that there is a variable time lag in the system. It's like living in an accordian world or rubberband time world where during parts of the maneuver, you may have one time lag, and in other parts of the maneuver, you may have other time lags. We've seen as much as plus and minus 80 milliseconds variation in the time lag because of the way the equipment was implemented, and the effect of that needs to be tested also.

2.3 Measuring Lags

DR. BERBAUM: The reason for asking about lags per se is that, as a committee, we're thinking about making some recommendations for retrofits that are based on these asynchronies, and because we are primarily psychologists, scientists, and physicians, rather than engineers, we may be recommending some things that really aren't reasonable. That's one of the reasons we're trying to get more education. In that vein, I would like to ask you more about the measurement of these lags. If we can't measure the lags in a simulator, and if we can't get those measurements often enough to know how well we're actually fixing something, or making the manipulation that we're trying to make, it doesn't make very much sense to say anything at all about lags.

MR. CHAMBERS: Time lag measurements, in an attempt to compare the simulator with the aircraft, are difficult to make, and therefore, there's very little data available. We've been trying to institute an easier time lag test that measures, basically, the fundamental throughput delay of the system, independent of the application software program that's in there, in order to do a comparison across simulators. We think that having a before, after, and baseline for different systems will help clear the air.

2.4 Currently Existing Lags and Asynchronies

DR. MAY: What do you estimate the lags in current simulators to be between--asynchrony between cues?

MR. CHAMBERS: I think modern simulators, newer ones, are running under 150 milliseconds total transport delay time. Many of the older ones are over 200. The cue synchronization differences in the simulators, I would not even want to guess, because we've seen variations that totally surprised us in the few tests that have been run.

DR. KENNEDY: Even in some new simulators?

MR. CHAMBERS: No. The newer ones are more consistent, because they all tend to reside under 200, but the older ones have numbers that have run out beyond 300 milliseconds in some cases.

DR. BERBAUM: What about asynchrony when you have that much total time?

MR. CHAMBERS: For the asynchrony, if you have a visual system that has a variable time lag, which we've seen in some of the more modern visuals, the asynchrony could become in excess of 100 milliseconds between motion cue and vision.

DR. DUNLAP: You're getting the visual to be so fast now that it's tending to react quicker than the inertial.

MR. CHAMBERS: In some of the visual systems now, they can lead the motion.

2.5 Inertial Response May Be the Ultimate Response Time Limit

DR. MAY: How slow is the motion?

MR. CHAMBERS: I guess most of the trainer motions have about a 1 Hertz bandwidth limit set on them. Part of that is for safety of operation reasons. Engineering guidelines say that the frequency response ought to be out around three and a half Hertz to get good motion cueing performance. However, by far, the large percentage of trainers have a 1 Hertz and below frequency response, and this leads to a certain amount of time lag that's fixed, and visuals are now, in some cases, getting better than that.

The other thing that's happened on some simulators is they've computed the motion at a lower iteration rate and therefore added more transport delay, but that's something that can be readily fixed. So assuming that you run the iteration rate in the computer high as the visual computed signal, then your ultimate limit will be the bandwidth on the motion platform. If you increase that, you will have to affect operating procedures because it becomes a more hazardous device.

2.6 G-Seats

MR. CHAMBERS: We've been talking about motion platforms, not referencing G seats. That's a different subject.

DR. KENNEDY: They're faster.

MR. CHAMBERS: They can be faster, yes. Most of the ones that are out there currently are much slower, but that's by design. They are air or pneumatic driven, and their purpose was for G cueing in the sense of G align, gravitational cueing, as opposed to onset cueing. They're really just now exploring in the research laboratory the use of G seats for onset cueing, which is what the motion platform normally does. Those are hydraulic driven and have a high bandwidth. Some even test as high as 10 Hertz.

3. The Possibility of Vestibular Masking

DR. DUNLAP: We had talked earlier about an experiment which compared motion that was, as Bob (Kennedy) phrased it, concordant with visual scene versus motion that was disconcordant, or opposite from the visual scene. In that experiment it didn't appear to make much difference. The person didn't interpret it as discordant. Earlier, Walt (Chambers) mentioned another related study, and I would like to get that into the record.

MR. CHAMBERS: There was an experiment done in the early '70s on the TRADOC simulator at NTEC, and they compared coordinated maneuver motion and random motion, break loose motion, and then no motion. They were comparing them on the basis of performance of the pilots with the aircraft. They found no difference between no motion and break loose motion with regard to his performing the task, but they did get some improvement with coordinated maneuver motion. However, there wasn't any testing done of the effects on sickness.

DR. DUNLAP: So random motion didn't harm the performance and it didn't help the performance?

MR. CHAMBERS: Right.

DR. DUNLAP: One of the suggestions might be to simply turn off the motion. It's just something else you have to keep in coordination, and if it really doesn't help the training, why bother with it? Then there's an opposite side of that coin, and that is perhaps putting in random motion. You can tell the vestibular system to shut up, vestibular masking, if you would.

3.1 Head Shaking

DR. DOBIE: The point you were making is an interesting one. It's been known for years by air crews, and it's only relatively recently crept into aeromedical documentation, that wiley old combat pilots, when they got disorientation, just shook their heads and got rid of the disorientation set.

DR. DUNLAP: So the idea is that if you had a bothersome sound what would you do? You would play some white noise and mask it. Maybe if we had vestibular input that should be saying one thing while you're actually sitting still, watching a scene--

DR. KENNEDY: Or they may be distracting vestibular inputs, because they're not good enough.

DR. DUNLAP: So if you put in random motion inputs, your head would say, well, I feel like I'm moving, but it's not helping me to use that or try to coordinate it with what I see, so turn it off.

DR. MAY: Let's take Bob's old gimmick about tapping on the eyeball. What is it, chewing on a pencil and tapping on the eyeball?

DR. KENNEDY: Chewing a carrot.

DR. MAY: You get mismatches between visual input. If you're driving down the road, chewing a carrot wouldn't disturb your performance, I wouldn't think, so we do tolerate some kinds of mismatches.

DR. KENNEDY: I think the particular suggestion being made here is that if a person were to have a series of vestibular inputs that are difficult to ignore, and were having trouble getting them in the way we do in the real world, that we ignore some of them. Say that you're in a motion environment, you've got the vestibular switch i: the on position, and the desire is to suppress the vestibular input as much as you can because you can't follow them anyway. You have a better input pathway, visual one, and you use it. You recognize you are in motion, the vestibular switch is in the on position, but you don't process all of those inputs.

Well, if we put in a noisy vestibular stimulus, it might be enough to minimize the conflict between visual-vestibular, because it may let you merely say, I've got a vestibular input. I can't pay attention to it. I'm going to trust the visual, and they, therefore, may not be in conflict.

DR. MAY: If what Walt said is right, it doesn't disturb performance to throw in random motion.

MR. CHAMBERS: Yes. It was the same as having no motion.

DR. KENNEDY: But both of these experiments were not in visual simulators.

MR. CHAMBERS: This was an instrument task, but it was the same as no motion. With good motion cues, he improved his ability to perform the task, but the random motion did not degrade the situation where there was no motion. Again, that same point of using this random motion to get you to ignore bad motion cues, because you can get some, indeed, erroneous motion cues from the platform when it's working. It can either be false bumps or stickiness causing jitter. You might try to interpret those as useful cues, whereas if you had vibration in there, it would help mask it. That's in the case where you have motion present. For the case where you don't have any motion present, maybe the vibration would help you ignore the fact that there is none-- again, desensitize the vestibular response.

DR. DOBIE: If you select a frequency on a higher end of the spectrum, and also make sure it's not too distracting, it's like the multi-stress situation where, in a strange environment driving a car, you switch the radio off first, to get rid of another distraction. It would have to be sort of a background random noise which is higher frequency, and not so distracting as to interfere with performance.

DR. BERBAUM: You wouldn't want it to be interpretable in a consistent manner, because if it is, then you're doing more harm than good.

DR. KENNEDY: I think random is the key.

DR. DOBIE: You're back to conflict.

DR. KENNEDY: Or noisy.

DR. DUNLAP: White vestibular noise.

3.2 Dependence on Particular Aircraft

MR. CHAMBERS: I think that might be true for fixed wing, but if you've got a helicopter that has an inherent vibration, you can't just go ahead and use that, because in some helicopters, vibration is an important cue, and it's very inexpensive to have that in there, in the sense that when you pass through certain air speeds, the vibration intensifies because of some resonant characteristics. I know they put that in vibration seats.

DR. MAY: Are these simulators that exist now? Do they approximate the amount of vibrations that occurs in the real world?

MR. CHAMBERS: Fighter attack aircraft that now are getting G seats also have what they call seat shakers. They use them for the shake, the stall or departure warning, but they can use it for any other vibrations that are characteristics of that aircraft.

4. Inertial Simulation Amplitude Limits

DR. KENNEDY: Is there a way that we can work in the notion you mentioned earlier about some percentage of the original into some combined motion, where up to some point you go with the best you can do, in hopes that what you're doing will characterize the environment. And beyond some point, you suggest 20 percent, if you can't follow then maybe this might be an alternative.

MR. CHAMBERS: Maybe I'm saying it another way, but we talked about wanting to have cue synchronization time wise within, say, 40 milliseconds. I think you're getting at the notion that, particularly with regard to vestibular, the amplitude of the input must be up to a certain level or it shouldn't be used; 10 percent of a cue may make it appear to be something else rather than the cue itself. In other words, it may not represent the cue well enough to be interpreted as the event.

You can use the analogy of the adaptable visual system, in that you can accept six foot Lamberts as daytime in a simulator, or equivalent to 600 foot Lamberts. So six foot Lamberts is representative of 600 as far as flying visually. But is two-tenths of a G that is given to you representative of 1.8 Gs? No, unless it at least gets to .4 Gs, it's not going to represent the 1.4 G. So there may be a minimum acceptable amplitude, just as there's a minimal acceptable temporal mismatch.

5. Freeze Conditions and the Smart Simulator

DR. BERBAUM: Walt, could I turn to another recommendation that we talked some about yesterday. What seems to be sickness inducing is the sort of terminal positions that pilots end up in within simulators. Freeze situations occur when they fly to the limits of the simulation or exceed some other critical parameter. Freeze is turning off the visual. Such sudden anomalous stops may be sickness evoking. On the other hand, if you fade the visual out slowly as if you had entered a cloud, then you may have other problems. You don't have any vestibular input telling you that you have, in fact, stopped, that you should perceive a stable situation, rather than continuing to travel on. The notion of a smart simulator, in terms of pilot error, that could interrupt or redirect flight, could prevent these anomalous motion situations which are potentially sickness eliciting. My question, then, is how readily could simulators get smart, where the simulation could predict difficulties and take control and guide the pilot back to a reasonable flight path or, [illegible]

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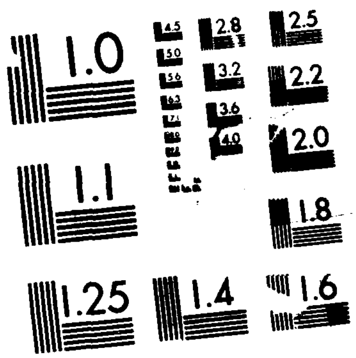

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he ended into a terminal state, shut off all the sensory modalities so that they were in agreement and nonprovocative.

MR. CHAMBERS: What is currently done with motion systems when their limits are exceeded is they go to the neutral position and then ramp down to settle on the ground. In other words, the neutral position is with all six pistons half extended. That's the midway point. So if you are in a high pitch attitude or side, when it gets the shut-down command, it does go to a program which currently is a certain ramp speed back to the neutral position, and then a slow decelerate to the all shut down position. Engineers have selected that ramp speed to be below sensory threshold. You're suggesting change that--

DR. KENNEDY: Make it concordant somewhat with what you're doing, so if you are about to hit the ground this way, the normal recovery from such a thing would be to at least pull the nose up, not for the platform just to go where it used to be. The platform going where it used to be is designed not to be a stimulus at all.

MR. CHAMBERS: That's correct. It's to remove all the stimulus, to shut itself down without your feeling it.

DR. KENNEDY: And we're saying that it does exactly the opposite.

5.1 Implementation

MR. CHAMBERS: It might be fairly easily implemented if you had a set of six, eight, ten different scenarios, and depending on the preconditions that were happening, it goes to that look-up table and it would call that particular shut-down procedure in place.

DR. KENNEDY: It might be possible to empirically determine the ones that are most likely to occur.

MR. CHAMBERS: Yes.

DR. KENNEDY: Also, you're talking about possibly using a voice to say to the pilot, okay, I've got it, as though he had a command pilot. All pilots know they're supposed to pick their hands up when the other guy says you're supposed to.

MR. CHAMBERS: Or request some information from him so he has to go attend to something new.

DR. KENNEDY: This is a job for voice.

MR. CHAMBERS: Yes.

6. The Feasibility of Particular Simulator Fixes

DR. KENNEDY: Let me ask the question: If we were to try to come up with some temporal relationship recommendations for the sorts of things that we think would be good, based on what we think might cause simulator sickness, what guidelines can you give us so that we can do it ourselves, short of having to sit with someone like yourself and discuss that back and forth, since we don't know what the simulation technology state of the art would make acceptable, reasonable, and costly. For example, retrofitting existing systems, is it a software fix? How might we accomplish that?

MR. CHAMBERS: There are some real cost constraints. Several of the old simulators are on computers for which the programs are in assembly language. To get the program in them, and to change that out to a new computer, would not be that expensive. But to rewrite those assembly language programs into even FORTRAN, some higher order language to put on that faster machine, is very expensive. That option has recently been passed over for that very reason on some simulator improvement programs. The cost of the computer was not the problem. The cost of the software rewrite was, because the original was in assembly language.

6.1 Data Base Changes and Working in Close

DR. BERBAUM: I would like to ask Walt how easy it is to make data base changes. Some of the things that I've seen in my small exposure to the Tustin simulator and also to the VTRS suggested to me that the only way to fix some simulations would be to rearrange the scene detail around those locations where you're going to have close ground interaction, so that you could more adequately represent the surface and the scale of the surface. Is that an option that could be exercised not only on some of these advanced simulators, but on training devices?

MR. CHAMBERS: Yes. It's not so expensive for those few systems that have a data base model or station, and an experienced and capable person to use it; for example, the AV8B has put that in place. I don't believe the CH53 has that. In those cases you have to go back to the manufacturer, and if he has a good source, he can probably make the modifications for reasonable costs. Reasonable costs might be five to ten dollars per edge changed. If he doesn't have a good source, he's almost going to have to start over and the costs are going to be very high.

DR. BERBAUM: That answers my question. I think that in the CH53, there are some places where you could change the data base a little bit and get a lot of improvement in reactions to it. For example, the runway where a lot of landings occur, and where a lot of experienced people get sick--I think it may be worthwhile trying to work on that a little bit.

DR. MAY: Does that imply we know what makes people sick in simulators?

MR. CHAMBERS: Scene content, of course, is in there, but I think it would be interesting to find out if, when you're working in close to anything, does that create a high incidence. You're working in close when you're near landing, particularly in a helicopter. During formation flight you can be working in close. The relative movement of the visual scene in there can be quite high.

DR. MAY: Do we have data on that? Do people get more sick during landings?

DR. KENNEDY: Just subjective reports; talking to people and flying in it ourselves.

DR. BERBAUM: There's a lot of reason to suspect you might have problems there because you're getting a lot of relative visual motion information, but you may not have very good surface definition.

DR. KENNEDY: We're talking about a helicopter, now, in particular. The closing velocities are small, but the amount of stuff that's in your visual scene, other than when you are at high altitude, is very large. They are big objects and they're close, and they have a lot of detail.

DR. DUNLAP: Is there also the case where there is so much scene content that they tend to be slow.

DR. MAY: More detail in the picture.

DR. KENNEDY: Or if there's more likely to be asynchrony.

MR. CHAMBERS: When you're in close, there's a lot of things in simulation that become very suspect, not only scene content but also any roll or movements appear as very large inputs. So, in addition to scene content, the aerodynamics and its validity of replicating the aircraft in that enclosed environment is known not to be as good. You've got a very good reference now to judge how well the aerodynamics are doing. In the case of helicopters, you have ground effect that sometimes isn't simulated as well as the normal aerodynamics. So in addition to the visual, it's the basic control simulation validity that needs to be checked out.

6.2 Symbolism vs. Realism

DR. MAY: If you can teach pilots to fly without simulators, what do you need simulators for? Obviously, because you get some benefit from them. They don't crack up as many planes.

MR. CHAMBERS: That's correct. As a matter of fact, that's in the Congressional Record. Navy testimony is saying that with regard to the F-14. I don't know that these discriminate between instrument simulators and visual or nonvisual, but the presence of simulators has been shown to significantly reduce the accidents in aircraft when they're being introduced.

The Army, in recent testimony, stated that they had erred in not having concurrent deployment of simulators with the Blackhawk aircraft, and they weren't going to make that mistake with the Apache; that the simulators would be there at the time the aircraft were deployed.

DR. MAY: I'm not proposing that you recommend, seriously, that they do away with all simulators. That's just not feasible. But if there's no hard and sound evidence that learning how to land a plane with horizontal and vertical stick versus a big scene is the case, then why not switch from an actual or virtual scene to one of these sticks, upon landing or something, if that's where simulator sickness comes from? You could go from the real world to a simulated world.

DR. DUNLAP: Or a symbolic world.

DR. MAY: Or a symbolic world at landing, or at that point in the flight where they get sick.

DR. KENNEDY: Almost a theme, so far this week, let's go simple because of simulator sickness. I'm not entirely sure that it will hold for all sorts of things.

MR. CHAMBERS: My comment would be that yes, I agree with going to a simpler scene, but what's there, try to keep as realistic or identifiable. A lot of that has to do with instructor and pilot acceptance of them, and they certainly have face validity for not introducing some unknown thing that then needs to be proven that it doesn't transfer negatively. So I would concur with possibly a simpler scene, but switching to symbology would take a fair amount of research to validate that.

6.3 Field of View and Exposure Time

MR. CHAMBERS: I have another thought along that same line of reducing the input stimulus--that's what we're talking about. The thought is that for those pilots that have a problem or for pilots that have a problem in certain task areas, reduce the stimulus input which might be reducing the field of view.

DR. BERBAUM: At least temporarily.

MR. CHAMBERS: At least temporarily, for that task.

DR. KENNEDY: Or the amount of time they spent.

MR. CHAMBERS: Or the amount of time. It could even be a choice that's selectable by the pilot. For example, based on his prior experience, a pilot selects mode B, which means he will only use the forward window during landing. It may be that the skill level he takes away from the simulator is a little less, which he will make up for in the aircraft, but he won't have the sickness.

6.4 Downtime Regulations

MR. CHAMBERS: This may be a way of getting rid of the downtime problem where, after he comes out of the simulator, he can't go in the aircraft for 12 to 24 hours because of some known history incidences. It might be a way of dealing with that, too, which, incidentally, is a problem for the instructors, sometimes more than for the students. If the instructor needs to take another student up on an aircraft hop, if he's just had one in the simulator, does that mean he's not available for aircraft instruction for 12 to 24 hours? That's another side of that coin that I don't think has been talked about.

DR. DUNLAP: Who sets those rules and how do they do it?

MR. CHAMBERS: It is my understanding that it's the option of the flight surgeon at the base.

DR. MAY: What were the problems that made them do that?

DR. KENNEDY: Sickness.

DR. DUNLAP: Is it sickness or is it just a rule that if you've flown a simulator you may not get in a plane for 12 hours?

MR. CHAMBERS: I think it was based on some experience that had happened either at that base or for that type of aircraft, and was communicated to the flight surgeon. There had been some reported cases of aftereffects, and this was to get around that.

DR. KENNEDY: What's happened traditionally is there is an incidence, the person who has the responsibility for the simulator communicates that and it gets to the squadron. The squadrons typically call in the flight surgeon, who is the local person in charge of such things. He will communicate with the Bureau of Medicine and Surgery, who will then, in one way or another, suggest that he put some kind of limitation on what gets done. Then those things are put out by dispatch, and it becomes a regulation that anyone who does this will then, from now on, do that. That goes throughout the Navy to other simulators of the same type. The line part of the Navy also can prescribe flying criteria.

DR. DUNLAP: But it's a matter of opinion, based on a few incidences, and it's not based on a lot of collective data.

DR. KENNEDY: But it becomes a regulation enforceable by the medical department on the line. It then becomes something that the line cannot not do, and therefore, limits the tempo of operations, and becomes a problem that gets everybody's attention. So in terms of problem definition, that's where you start.

7. Novices and Experts

DR. DOBIE: Can I ask another question in relation to your data base with regard to naive subjects. Have you collected any data on kids just doing similar things to aircraft flight simulation, in bars and compasses, because I bet there isn't any simulator sickness. I stood in the little Sandbar at UNO, and you see kids flying high performance airplanes between hills and around corners, who have no problems at all, because nobody has told them about simulator sickness.

DR. MAY: They are self-selecting.

DR. DOBIE: To some extent. But that's an interesting point. My experience in simulators, over the years, has been that the problems are usually with experienced people. They have a preconceived idea about the real world, and this simulator, if it doesn't produce the real world, creates a problem.

I remember when Alan Benson and I looked at the Lightning, one of the problems was that the simulator, in the roll access on finals, was totally different from the aircraft, and they couldn't get anything in their mind other than that. This was so important that they just couldn't cope with a simulator, but a naive guy wouldn't know the difference because that's the way it works.

DR. BERBAUM: I think it's pretty clear that naive and experienced people get sick for very different reasons.

DR. KENNEDY: But naive people do get sick.

MR. CHAMBERS: Isn't it predominantly systems that have wide visuals--wide angle visuals--where the naive ones get sick?

8. The Length of Sessions

DR. DUNLAP: That's what Jex said, and he said it in an interesting context that gets back to your video game question. He said when they first put in Cinerama, you know, wide field of view which you get at EPCOT, they found that people would get sick and throw up, and then everybody is sick. They solved it in a simple way. They limited those things to 15 minutes, and in 15 minutes you could get the sensation where you thought, wow, I'm really going, but then they turn off the movie and you got out of it. They did the actual research to find out how much of this you could take, which raises the issue of perhaps keeping flight simulations to 15-minute segments, and interrupting them with some static stuff that brings you back to earth.

DR. MAY: How long are simulator hops?

DR. KENNEDY: The longest that I know of is four hours. The shortest are 0.8, 0.9 hours. They have 2-hour simulations on the East Coast and 3-hour ones on the West Coast, and they tend to have more symptomatology on the West Coast than the East Coast I believe, because of the length of the simulation. That is for similar operations that are not exactly comparable. If you do one hour or less, I believe you have far less sickness. I think if you do two hours or more, you will have far more, just on the basis of what might be an objectively equal event.

DR. MAY: Is it at all feasible to run 15 minutes?

DR. KENNEDY: It can be.

DR. BERBAUM: You could go at it from the other direction. You could say if you're having incidents, then whatever you are using as your interval, break it in half and take a break in the middle.

DR. KENNEDY: Or if we could find out which maneuvers created the most problems.

DR. MAY: This is coupling with Tom's stuff again. You say to the person, when you first begin to feel anything, take a break.

DR. DOBIE: Fairground operators have come up with a rule of thumb that you run for three minutes on a fairground device. If you give them less than that, they feel they haven't had value for money. If you give them more than that, they'll get uncomfortable and may get sick, and that doesn't do your business any good, so they have come up with an arbitrary rule of thumb.

DR. KENNEDY: That's Andy Irwin's--

DR. DOBIE: Andy Irwin, yes. You know that.

DR. KENNEDY: He's got a paper called "G Is Amusing."

DR. DOBIE: So that's a similar idea. If you can't simulate exactly what happens in the airplane, back off, to the limits of the human animal.

9. *Technical Question and Answer*

9.0 Raster Direction

DR. MCCAULEY: One thing that came out in that Monterey conference on simulator sickness was the display is written in about 15 milliseconds and in some simulators two side-by-side displays are actually written in different directions. This is over such a short duration, like 15 milliseconds or so, that you can't actually consciously perceive it. However, somehow our sensory processes may get confused by these adjacent screens being written in opposite directions.

MR. CHAMBERS: Almost all options you can think of are currently being put into simulators. Most of them are rasters which scan from top to bottom if it is oriented horizontally. But some of them stand vertically, so they go from left to right. So they will be painting pictures in different ways, but the 15 milliseconds is basically the 60 Hertz, 16.6 milliseconds to scan out half of the resolution. You know, it is an interlaced picture. They scan out every other line, and come back the next 16 milliseconds and scan out the next set, which is the way home TV works. The other thing that they do is some of them during the retrace come back and stick in a whole bunch of point lights, like in a calligraphic system, and then will paint out the raster. Others are calligraphic in that they paint out a whole lot of lights and come back and dither in little pieces of surfaces.

DR. DUNLAP: So there would be no raster in that picture.

MR. CHAMBERS: Well, each little building -- the side of the building is a little mini-raster. So, they put these little mini-rasters in and that's what make the surfaces. Otherwise there would be nothing but points of lights and lines for horizons.

DR. DUNLAP: This is off the wall, but electronically I don't see why it wouldn't work. You could paint the first frame this way, second frame this way, third frame this way (Indicating). Wouldn't that lessen the whole concept of raster?

MR. CHAMBERS: You might do that in some systems but it would make them more expensive if you did that. They are set up as resident systems; the rasters are to be scanned in a certain direction. Also, it would cost more to build one.

DR. DUNLAP: Essentially you would have two systems taking turns on the frames?

9.1 Iteration Rates

DR. KENNEDY: Are they all 60 Hertz or are some slower?

MR. CHAMBERS: The raster systems are all 60 Hertz, but keep in mind the entire picture isn't painted except in 30 Hertz because at 60 you are painting an alternate field. So you see the whole thing in 33 milliseconds except for the calligraphic type. The ones that draw all the other points and come back and dither in the surfaces, those just keep drawing until they are through. They may take 45 milliseconds to draw the entire picture. They are part of the source of the variable time lag that we have seen in some of the systems. If there is a lot of scenery, more detail, it is a longer lag before it is drawn. And, therefore, it doesn't start the picture so the iteration rate is no longer 60 or 30, it is something like 20 or 15 for a little while.

DR. MCCAULEY: Once you get up to around 20 or 30 or 40 milliseconds, we are talking about detectable perceptual events. It sounds like the system is operating in the time domain that is near the threshold of what people might be detecting.

MR. CHAMBERS: There are other types of systems; the CH-53, which has one of the most simulator sickness cases, has a buffered output. So, it's drawing this scenery in memory while it is scanning out the previous locations, and it will scan that out at 30 Hertz. That's repeated. If it takes a long time to fill up the other buffer, then this one is repeated maybe twice or three times until that buffer is fed out. Then it's transferred over, and it's read out.

DR. MCCAULEY: So it will jump.

MR. CHAMBERS: It will jump. And we have videotapes of that unit.

DR. KENNEDY: We have one here.

MR. CHAMBERS: Keep in mind that the air combat system almost doesn't have any rasters, at least none that you could really distinguish. That is, because the horizon background is just a point light projection through a pane of transparency which the horizon rotates mechanically with no rasters. The target projectors are only about 15 degrees maximum, and sometimes shrink in size, so the ability to see the rasters lines in there is very difficult and that only contains the aircraft that is being projected on this nonraster background. One thing to keep in mind with regard to flash or flicker is that as each pixel is painted, it comes on so it goes from nothing to bright, and then it will decay to 10 percent of its value in about 20 to 25 milliseconds. Each pixel has that kind of a characteristic.

DR. BERBAUM: The duty cycle is going to be something like two-thirds on and one-third off.

MR. CHAMBERS: Yes.

DR. BERBAUM: You don't see flicker in those.

MR. CHAMBERS: No, in the air combat simulator when the target is moving roughly about 100 degrees per second, if they do a fast roll, and it comes across the top at about that velocity, you'll begin to see a double image of the airplane. That just doesn't happen often. You are purposefully maneuvering the aircraft tightly to come into some new position, and then you try, and it's very stable after that.

DR. MAY: Does it look like diplopia would?

MR. CHAMBERS: I don't know. It begins to separate into double image. I relate it to something similar to sigmatography, double image effect.

DR. KENNEDY: Since this is Walt's last session, are there other equipment features that we want to ask him about?

9.2 G-Seats

DR. MCCAULEY: I wonder about the other sources of motion information that are sometimes used such as G seat and G suit. What is your opinion on the engineering excellence of those systems, lag times relative to the motion base and visual, and do you think that has any contribution to the problem?

MR. CHAMBERS: Well, in the air combat units they do have G seats and G suits in them. But there's nothing to excite the vestibular system at all in those. The helicopters are on motion platform, the magnitudes of the displacements quite frankly don't excite the vestibular system very strongly. Certainly not as much as the airplane. Both of those have seat shakers in them. Most helicopters have some sort of vibration input, and they put seat shakers in the fixed ones, too.

DR. MCCAULEY: There was a fellow named Frank Cardoules out at Monterey who was talking about his participation in development of some of the G seats. He pointed out that that could be a problem because of the lag time. I think it was particularly pneumatic seats where he said there was a definite lag. He was wondering whether or not even though it doesn't excite the vestibular system it is another source of information about your dynamics. So, if you have differential lag times between the visual and your pneumatic G, that might not be a problem.

MR. CHAMBERS: Yes. The G seats were originally designed to give gravity line cues so as you roll the aircraft or pitch it, you get a gravity force working on you. That is a fairly slow changing--that is what they were designed to do. They were never designed to give accelerations from aircraft. Those onsets are much faster. That's what the motion platform was designed to give.

9.3 Washout Motion Equations

DR. KENNEDY: I have a question about the equations of motion used to generate the tilts and the returns. Are those average values and do they represent threshold data for various kinds of changes in position? And then they are probably tweaked and made to be realistic according to who puts them together in the first place? And then tweaked and tweaked and tweaked. Are they all documented as to what they are? Are there rules for them and are they all the same throughout all simulators?

MR. CHAMBERS: There are guidelines and rules. The washouts, of course, are supposed to be sublimal. There are a couple of good reports that document what they should be. Of course, it is a matter of the units that are out there staying in calibration and having been put in by proper design. We know a few cases where they wanted more motion cueing and then cracked up the cue game which raises the washout above your threshold. Also, you can feel near the washout. In those applications, the user unit chose to do it that way because they felt the cue they were getting was important, and they lived with the false cue indication that comes in with that. So it's a matter of user choice.

DR. KENNEDY: We should probably do more with that. We should probably look at that better. Are the publications you're talking about MTC publications?

MR. CHAMBERS: Yes, we have a very good summary out for motion platforms. We also put out a summary on G seats. It's a couple years old now, but it summarized all that there were, and what they were being used for, which is mostly not in the literature. Cardoules has some good papers out too on those.

DR. KENNEDY: My reasons for bringing this up, I think that there are average values both for perception of movement as well as perception of washout. That is, I think that there may be an average response that we all may have as a group, but I will bet that the more sensitive among us have a different threshold than the less sensitive among us. And if those are average values, then this can be a source of problem for the more sensitive. The same thing is true of washout. It may be on the average, below threshold, but it may not be below threshold for all people who are exposed in the simulator.

9.4 On Published Specifications

MR. CHAMBERS: One other area to mention is the aircraft aerodynamic computation development. Along with that is control stick displacement trueness to the aircraft. Those are two areas pilots are very sensitive to, and can generate, "I like this thing," or "I don't like this thing," more so than all the others we have discussed. He is used to giving this much throttle and this much stick to get to a certain place in time. If he doesn't get there, then it's not my airplane.

DR. KENNEDY: Essentially what you are saying is if simulators are about to be designed the process would be you take these numbers which are available from all these published sources, you generate how they are going to be, and then it's evaluated during the course of its acceptance by pilots. All the time people are riding in it and using it, and it is being tweaked to be adjusted to what those potential users claim is what it should be. So it may not be entirely what the original equations suggest that it should be once you get it out on the line.

9.5 Tweaking for Perceptual Realism

DR. MCCAULEY: My understanding of it is that the engineers can set it up to be veridical with respect to the aircraft so that a certain amount of stick displacement will get you a certain roll rate.

DR. KENNEDY: Only in the visual.

DR. MCCAULEY: I'm just talking visual, and the pilots will get in the simulator and say, no that's not right, it's too sensitive. You have to back it off. So they tweak it to perceptual realism.

DR. DOBIE: Generally speaking, when you go around, pilots complain about the equipment not feeling like their airplane. It doesn't feel the same, and you are quite right, Mike (McCauley), it was the same to us it was put to the aircraft engineering spec, but it didn't feel like that to the student.

DR. MCCAULEY: One wonders why.

MR. CHAMBERS: It may be the same as the visual picture that is perspectively correct, but the pilot says, hey, look, I am too high. You know, there are two light points out there or a triangle of light points, and you get in there with the theodolite, and you measure the distance exactly right for the 7-foot eyeheight sitting on the ground, and the pilot says it looks too high. There may be something in, and maybe it's because it's contained in this ring. It's a TV set sitting in front of you, and it makes things look smaller. You think you're further away, whatever. There is some perceptual error because of the situation he is viewing it from. Or it might be the chair tilt position or head, previous head position, maybe there is something about the simulator environment that causes dynamic interpretation shifts, also.

For example, on the Harrier simulator some years ago in England, there is a research unit they had a very sharp horizon, and it was on a dome, and the pilot complained the stick sensitivity was too high. They froze the horizon, and he said now it's okay.

So, you reduce the cue that was coming in. He said now it's like in the real world. It was a visual adjustment rather than an aircraft air dynamic change.

9.6 Landing High With Lack of Scene Detail at Cherry Point

DR. MCCAULEY: Just a little more anecdotal support about one of the newer helicopter simulators at Cherry Point. It was a fairly new one, and I remember when I was talking to three pilots there who said they definitely feel higher in a simulator than they do in the aircraft. I was trying to get them to talk about negative transfer training and that's the one thing they came up with. They have a little bit of trouble in landing if they fly the aircraft later the same day because in a simulator they feel high, and so, they have a real hard time landing the simulator. They go down to where they feel like the wheels ought to be touching.

DR. DOBIE: Lack of detail in the simulator will make you feel high.

DR. KENNEDY: They can't get it down.

DR. MCCAULEY: Yes.

9.7 What Simulators Produced the Highest Incidence

DR. MCCAULEY: I think that helicopters are particularly interesting because it seems like it is near threshold phenomena where slight changes are important to the person. I think that you can get more sickness with lower intensity stimulation in a hover situation, for example, than you would in a fighter aircraft where you are simulating high G, high speed maneuvers.

MR. CHAMBERS: Well, the most commonly or the largest volume of reported incidences result from those turning and twisting maneuvers. The other is air combat maneuvering simulators. Now, of course, in that case there is a lot of head motion involved in addition to the wide vision.

10. Summary of Impression From the Conference

MR. CHAMBERS: Here is a summary of where I felt I was with the information that I have been hearing. It goes as follows: (1) Sickness in a simulator may occur when the illusion of motion is created. It most commonly occurs when vection is present from wide angle vision. The likelihood of sickness increases with increasing magnitude and duration of the illusion. (2) Magnitude of the illusion for an individual depends on his response sensitivity and on his stimulus magnitude. The likelihood of sickness may be reduced by (A) reducing the stimulus magnitude and/or duration, and (B) reducing the individual's response by either of two categories: One, reduce the individual's illusion motion, and under that category could be done by adaptation or through education and preconditioning. Habituation through repeated exposure masking at the stimulus through a variety of illusion interferring mechanisms and medication. The second area would be to upgrade the stimulus group so that the motion illusion is more complete and consistent with prior experienced conditions considered normal. That is not sickness inducing for the individual. This may include all of the following or some subsets. (a) Increase the vestibular and somatic stimulus to an adequate level. (b) Reduce the stimulus temporal lags to within less than 100 milliseconds to their normal/expected response. And (c) reduce disparity between stimulus cues to less than 40 milliseconds. To these three groupings I have indicated you would need to rank the confidence in the fixed effectiveness, the impact of it on training effectiveness, and thirdly its cost. That would be across the three categories of reducing the stimulus magnitude, secondly reducing the individual sensitivity by either reducing the illusion or upgrading the stimulus group. Each of those items needs to be interpreted in all the context of the discussion that we have been having.

CHAPTER V

Discussions with Jim May, Ph.D. and Thomas Dobie, M.D.
September 25, 1985 - Afternoon Session (2)
September 26, 1985 - Morning Session (continued)

DR. BERBAUM: To start things, I think in this session we would like to focus on Dr. Dobie and Dr. May's contributions.

1. Activities for Readaptation to the Normal Environment

DR. DUNLAP: I've got a question. What kind of activity would be most effective in bringing people back down to earth after simulator hops? I think Fred Guedry recommended a ping-pong game.

DR. DOBIE: That's an interesting question. I suppose Fred mentioned ping-pong because it involves a lot of head movements, a lot of moving around.

DR. KENNEDY: You could rig a videogame up. You know, it could be a paddle type thing. It could be done with existing systems; maybe not easily, but it could be done. But the real question is would it be useful to enter into some kind of nonaviating activity as a method of getting yourself unwound from having been enveloped in this dynamic environment, as a method of coming back to normal.

DR. DOBIE: It would be more cost effective to pair up students so that when one is playing ping-pong, the other is using this sophisticated piece of equipment, rather than have somebody sitting in there, wasting his time by playing ping-pong. I think you would have difficulty selling misuse of the simulator. I think they would also, in my view, get better stimulus of a nonprovocative type, if they actually were playing real ping-pong, if you want to use that as an example.

DR. MAY: What about just stopping everything and let them read a book?

DR. DOBIE: Yes, but I think if you get the people out of the environment, it probably has a double advantage. One is you could use the equipment.

DR. BERBAUM: Another thing is that, if you are getting adaptation within the simulator, particularly if the simulator has complexities such as helmet-mounted displays where you may get actual recalibration of the vestibular ocular reflex, having a game where you actually make a lot of head and hand movements would serve to recalibrate the subject better than a more passive activity.

DR. MAY: It sounds like we're working out of a model that says the source of motion sickness is perceptual conflict, that you can adapt to this perceptual conflict. It's during the adaptation period that you do get seasick, and when you've adapted, you don't get sick.

2. Collect Data at Simulator Sites in the Survey

DR. KENNEDY: I think we should make the survey pay off. We have over 100 people at almost all of the ten different simulators, so we have a pretty fair idea of where the trouble spots are. What we could do is pick one or two or three trouble spots about which we feel relatively comfortable, that the incidence is beyond 50, and see if we can, by the application of some techniques, reduce it.

DR. DUNLAP: Walt (Chambers), I mean you have the actual experience with these simulators, maybe more than most people. Can we have a checklist that they check before entering the simulator, and then a checklist of--did I get sick or not, would be the simplest question, or did you feel awareness or not. Maybe a one-page thing that is routinely given every time you go in a simulator, some standardized thing. Can we do that?

DR. DOBIE: If you do that, it has many disadvantages, because what you are, in fact, saying, you are re-enforcing all the time that this person is going to have a problem.

2.1 Duration of Exposure

DR. DOBIE: I sincerely believe that if you're going to look for a time that will be satisfactory for most people, you want to find that as quickly as possible, and then ignore the problem. If you are able, at this moment with your information, to pinpoint what sort of duration seems reasonable, then that could short-cut the system. Then what I try to do with individuals after--and if we do this in a larger way, you can do it with some sort of formal briefing without involving an individual like myself--I do it myself because I'm dealing with small numbers. You then emphasize that the individuals vary. What you want to find out initially is their threshold; threshold, meaning when they first start getting responsive. You say, this is a normal thing. We just want to know what your threshold is. Once we have established that, then you forget about it in the sense that you then preprogram the duration of exposure, but you never ever, when they come out of the machine, say how bad did you feel.

2.2 Problems with Self-Report - Observational Alternatives

DR. DUNLAP: Maybe what you say is what did you find wrong with the machine.

DR. DOBIE: I tried to do a remote program once. I hadn't time to write all this, so I went down and I briefed one individual, explicitly, what to do. But a physician came back from vacation who said, "Yes, I worked on this at RAM. I know about this. Oh, he's not giving them the Pensacola questionnaire. That would help. It would speed things up." So he started to issue the questionnaire: "Tell me what your sickness responses were," and the guy went backwards from that minute on. I came down to find out why. I said, "You must have changed something."

DR. KENNEDY: It's the Pensacola questionnaire.

DR. DOBIE: No, that's only a for-instance. It happened to be the Pensacola questionnaire. But he was asking, "How sick do you feel? Do you feel bad? Do you have symptoms?"

I came down and just removed this thing. I said to the guy, "How are you getting along?" And ignored that run. I just said, "Look, your progress is--you must be very pleased. Look how marvelous you're getting on." He went back in again and never turned a hair after that, having had a day and a half of disasters. He just went backwards because he lost his confidence.

DR. MAY: It seems to me that if the issue is simulator sickness, let's deal with it. Nobody wants to ask anybody, or get any sort of index about whether these people are sick, until they get out and voluntarily come up and complain. By that time, it's too late. They might be very sick and very upset about it.

DR. KENNEDY: The survey had people on site, for the most part, full-time, monitoring the output of the simulators, so it was head-to-head observation. It is questionnaire responding, but it is, here, fill out the questionnaire. Here, walk a straight line. Here, take this performance test. So the data base is based on those three postmeasures, as well as a premeasure. Admittedly, suggestion being what it is, you may have a higher or you may have an unknown. Admittedly, self-report forms have every one of those problems; nonetheless, that's the data base. If we have a worthwhile idea, whether it is a modification to the person or to the machine, I believe that someone would go to the field site.

DR. DUNLAP: I've got an alternate suggestion, following up on what you said. Let me try an alternate that gets around the problem. There's always a monitor, right, a guy that runs the show.

MR. CHAMBERS: Either an instructor or there's an operator.

DR. DUNLAP: Either an instructor or an operator. That's where we get the data. They are instructed to fill out a checklist: Did this guy leave the simulator, by observation. So we're not asking the person who is in there flying to collect data. That, together with the timeout button that says, hey, if things get bad, just press the timeout button--you can write down when the timeout button was pressed. I think those two bits of data that are observational, as opposed to self-report.

DR. KENNEDY: I don't believe we could limit ourselves to automated data acquisition any more than we ought to go and put a man there all the time. I think that it ought to be a function of the kind of data we want to collect. If we think we can get it automatically, fine. If getting it automatically would ruin it, then let's propose we put a man there. But I don't think we need to worry about that. I think we ought to worry about what things we want to know.

2.3 Exposure Duration and Incidence of Sickness

DR. MAY: I want to know this. You've got data via a questionnaire or whatever, on what percentage of people get sick. What percentage is it?

DR. KENNEDY: It's as low as 10, I think, and as high as 60.

DR. DOBIE: Do you have anything for comparable simulator situations to relate that to duration of exposure?

DR. KENNEDY: It's in the data base. We haven't pulled it out.

DR. MAY: Then this whole thing is on simulator sickness, right? I mean it's a problem. That's why we're here. How big is the problem?

DR. KENNEDY: It's as low as 10 and as high as 60 in the simulators we've looked at.

DR. MAY: As high as 60?

DR. KENNEDY: But we're talking about a change at score of two on a seven-point scale. That means probably the equivalent of noticeable discomfort. So 60 percent have noticeable discomfort in simulator X, and that's the worst. That's all of the exposures, recognizing that some exposures are on the same people. So we've got 1400 exposures, we may only have 600 individuals, so we're still going through the data base.

DR. MAY: Do you have it on your first session?

DR. KENNEDY: Not always on the first session.

DR. MAY: What percent on the first session?

DR. KENNEDY: We don't know yet. I can give you a guess. The first session is going to be the highest number and you're going to get a learning curve from there. That will be modified by the amount of kinematics. In one or two cases we have increased incidence as they go into increasing aerobatic requirements, so everything happens the way you would guess.

3. Dobie's Therapy

DR. KENNEDY: Let me make a suggestion: First, that Walt (Chambers) answer the question that we both asked him, and then after that, that we let Tom (Dobie), for the record, tell us what it is he does, so that we get that in, so at least when we start asking questions of ourselves, it follows on the meat.

3.1 Feasibility and Off-Line Training

DR. KENNEDY: But anyway, you know the question. How feasible is what we're up to in terms of getting it done?

MR. CHAMBERS: The difficulty is that we're dealing with a schoolhouse situation, and they do not want interruptions. They have a syllabus that involves the individual in a simulator for a certain amount of time. And even when we go in to put hardware mods to update that simulator to match the aircraft because of some avionic change, they want it done on nightshift or weekends. So anything that interrupts their schedule has to be almost--in other words, the situation has to be almost to stop work, to talk about interrupting their schedule.

Tustin had such a situation for awhile, which is one of the reasons they invited us out, and we got a lot of data at that site. I believe they changed some of their use procedures and their incidences aren't as high, so they don't consider themselves in a stop-work mode anymore. I think Bob (Kennedy) wants to identify what are all the measures or kinds of things we ought to try to do, but then when they are selected, they're going to have to be quite nonobtrusive in most sites.

DR. DOBIE: You can understand the trainer problems. They want answers that fit in with an effective training program. They've got a tight training program. I've made recent proposals that we should not use that simulator for things that could, perhaps, be usefully done outside the simulator. We might try to fit these early training confidence building procedures into a totally different part of the syllabus, unrelated to the simulator, but linked to it.

Now, we have a little training session here which everybody gets, and that includes initial briefing. It includes a gadget, which we could easily devise any kind of gadget, which would train them to handle these problems before they get into the simulator. I suggest that would be more appealing to a training system than disrupting, totally, the training effectiveness of this highly sophisticated and highly expensive piece of training equipment.

DR. MAY: If I'm reading between the lines, Walt, their attitude is simulator sickness isn't really that much of a problem, because we don't wash a lot of people out of school for it. We don't want to devote a lot of their training time to avoiding this minor problem. We would rather select people--

DR. KENNEDY: It needs to be underscored that even with the data base we have, I believe the following is probably a reasonable assessment: 90 percent of simulator sickness is experienced by 20 percent of the people. It's probably not something that everybody gets even under the worst circumstances.

DR. DOBIE: Then you do it the other way, which is probably better, and goes along with another thought I have. That is that people have got a problem, it's probably easier to deal with it than do a preventive program for everybody, some of whom, 80 percent may not have it, and the other point at issue is that you're not chewing up so much time. You don't have to do it in the simulator.

3.2 Engineering Solutions vs. Human Solutions

DR. KENNEDY: Simulator sickness is polygenic and polysymptomatic. It is going to be due to more than one cause, not only in the different simulators, but also due to more than one cause in a particular simulator. So it may be that one person that gets sick in a simulator for one reason, and another person, for another, one of which may be benefitted by an approach such as you propose, and another one may be benefitted by making that simulator simulate, in an engineering sense, better, according to the specifications that were laid out for it.

All of our recommendations should, up front, recognize that there is no one solution to the problem. So there are engineering fixes, and I think we know certain things that ought to be fixed, and I think there are some others that we have hunches about, but not sure about. The same thing is true with modifying the person.

DR. DOBIE: I agree with you wholeheartedly. Given an existing situation, I believe a lot can be handled by dealing with the person. But the other part is equally important, and varies between individuals as to how relatively important these two things are, and I've got evidence of pattern responses to show this. But there's going to be a simulator which we can't modify. Then we're left with dealing with the other part of the problem, which is the cognitive responses of the individual which, in my view, can do a hell of a lot, and does a lot more for some people, more quickly, than it does for others. I agree with that, too.

3.3 Avoid Avoidance Learning and Promote Habituation

DR. MAY: As I said before, perceptual conflict, some people believe, leads to motion sickness. We also believe that you can adapt to that perceptual conflict, and after you've adapted to it, you're no longer motion sick or you're not prone to motion sickness. What Dobie says is that while you're trying to adapt to a situation like that, you get motion sick and you go through avoidance learning. You say I don't like this. I know it's going to make me sick. You become anxious before you ever get in the simulator or the situation, and it becomes positive feedback, so the problem gets worse in the beginning. So if you take preventative measures of the type that Tom (Dobie) is talking about, you get rid of this cognitive positive feedback loop that happens in the beginning, and then adaptation can occur more rapidly.

DR. DOBIE: Right.

DR. MAY: I agree that it's a good idea to work on getting rid of the perceptual conflict, but there are physical limits to be able to do that.

DR. DOBIE: That's right.

DR. MAY: So let's work on an individual to get them to the state where they can adapt quickly, and then explore what we need to do to promote adaptation to a simulator, and let's also work from the other side. It's a typical human factor problem.

DR. DOBIE: In a way, there are two elements here, and one overlays the other. I believe the reason why people vary widely in their responses is because of their previous experience, which is many things. An experienced pilot or an astronaut may complain about the simulator not being realistic, feeling funny, not seeming right. Sometimes it's more stressful to them because they are high achievers and expect to do well.

I've put instructors on a simple turntable, and they've told me afterwards they felt disorientation for two days. I don't believe that for a minute it's their set. What my treatment does is get rid of their anticipatory problems so that they are back down to reacting as the people who were apparently resistant. They're not resistant; they just don't have these overlay problems. So eventually, they can start from the same point onward.

3.4 Supporting Evidence

DR. DOBIE: What is the supporting evidence? Well, my earlier work published some time ago, with using a vestibular stimulus. I was flying the airplanes and I was advisor to flight surgeons and physicians. I was confronted with the fact that there was a very large motion sickness problem. If you ask the instructors, they will often say, no, there isn't any problem at all. Go and look at the books and you will find the reports in there, but they've forgotten. I thought, well, what do I do about it. Originally, I though of excluding people who were apparently exclusive to the motion sickness, and this, naively, seemed a way to do it, thinking that maybe there is something special about these people. Luckily, I didn't go that route, because I believe it would have been totally destructive. Eventually I got into the idea of adaptive training.

One of the first guys I had in my training program subsequently broke down and was grounded permanently because of motion sickness. I retrained him and put him back, and he turned out to be one of the best pilots we had ever had, which is why I think maybe there is merit in going the route of treatment rather than gross prevention programs across the fleet. Strangely enough, one of the things that worries me is that if they have a problem, and you cure them, are they going to have any hang-ups about it. On the contrary, they had no worries about it at all. They were proud of the fact that they had succeeded. So I then thought the obvious thing to do is look for people who have been grounded permanently. So I took 50 unselected cases, the next 50 off the line. By unselected, I mean as soon as anybody was grounded by the executives, where there was any label--which was, of course, not put on by me--I said I'll take them. I took 50 in a row and put them through this training program. I felt that from all this sort of little bits of information we had about the problem of motion sickness in the past, we knew that habituation or adaptation was significant.

3.5 Stress Sickness vs. Motion Sickness

DR. DOBIE: But it also struck me that an individual can be sick in an airplane and not be motion sick. This is, in my view, a very important thing to remember. You see, by various definitions seasickness, air sickness, amusement park ride sickness, all have the same signs and symptoms. That immediately suggests a particular mechanism. But if you take an individual and put him in an examination environment, you can induce an autonomic response, which is the same. So how are you to know that because a person is sick in a simulator or in an airplane, that he's actually motion sick, rather than being stress sick. You can be stress sick if you are a high achiever, and you've got an instructor sitting there that's behind you in an airplane or a simulator, and you're not achieving, in your mind, high enough to satisfy him. That can make you nauseous or it can make you sick.

Since I couldn't tell which individuals were which, the easiest solution was to ignore the problem and assume that there is an anxiety factor--whether it is most of his problem, as in the stress scenario I tried to give you, or whether it's minimal in this individual, and he really hasn't habituated yet. Let's assume both are present. So how can I treat that? First of all I have to show him that his responses are normal, and at the same time, show him, by some method, that he is, in fact, capable of adapting, whereas at this moment in time, he probably thinks he's not capable of adapting. But at the same time, you don't need a sophisticated gadget to give them these feelings.

3.6 Confidence Building and the Gadget

DR. DOBIE: So what I did was I simply gave these individuals a 50-minute session. That session was a confidence building counseling where he started to identify with normality. The way I did it was with all the simple little cues and gimmicks that you can train anybody, I made him bring every paper he had of his medical history, his simulator history or his flying history, as the case may be--bring them all to me. I take them, and very theatrically drop them on the desk. Then I sit and talk about motion sickness or sickness in the air. I don't talk about him. I obviously never open the envelopes. The whole idea is that I cover all aspects of normal human responses to a flying environment or a simulator environment, as we are now interested in. Then at the end of that, you get up and start to walk away, and then pause and say, "Oh, you brought all of these. Let's have a look at them." Then you go through his stuff, demolishing what he thought was the biggest problem in the world, but in fact, you have already mentioned it as being common to everybody.

So you say, "Oh, yes, you had a bit of that. Oh, you had that, as well."

So his problem is now brought right down. What you do is you observe him. He starts off in your office like this (Indicating), and when he finishes up in your office like this (Indicating), you've achieved the end of phase one. He's now relaxing and identifying with normality. That's the sort of approach I take. Then I say to him, you may or may not believe what I've said to you, so you need some evidence to satisfy yourself. Then I point out to them, I can do it in an airplane, I can do it in a ship, I can do it in a simulator, but they're too expensive. We don't have the time. I haven't got the time; you don't have the time. But I can produce a gadget which will produce symptoms. I say to them, I'm not going to teach you to adapt to stimuli, I'm going to teach you to live with symptoms. I'm interested in the efferent side of the loop, not the afferent side. By doing that, when you're confronted with any situation in the future which gives you these responses, then you will go into your act and say, yes, I've had all this before. This doesn't bother me. I know I can live with this; I did it on that stupid machine that this guy has. Therefore, if you can get him to believe that once he feels these responses, then it really doesn't matter whether you do the training in a simulator or on a cheap bench model. Also, it allows you to transfer protection across different stimulus modalities, which is the advantage it has over a pure adaptive training, in my view.

3.7 An Example

DR. DOBIE: It worked, highly successfully. It's been retested by my colleagues at Farnsborough twice, highly successfully. After that, I only had the opportunity to treat one sailor, who was so sick he said, "I refuse to go to sea ever again. I don't care if you fire me. You can shoot me. You'll never get me to put my foot on a boat."

He went back to sea. His first trip was on an aircraft carrier crossing the Atlantic, to do flight trials with the carrier. The crossing was so bad they couldn't fly an airplane off even once. They lost the Admiral's barge. They wrecked the superstructure. On day three he said, "I began to feel a little queasy on day three." This is the guy who was permanently blown away on motion sickness, and he hadn't been at sea for months, of course. "Day three, I began to feel a little queasy, but I said, oh, it's that same old junk that I used to get on this guy's turntable, so I just forgot about it and it went away." He said the place was swimming in people vomiting.

3.8 The Device

DR. DOBIE: I believe two things. To make my proposition work, it has to be true that it doesn't matter what device you use, it should transfer across these modalities. The second thing I believe is that it shouldn't matter whether you do vestibular mismatch stuff or visual, or whether it's an inter- or intrasensory mismatch problem.

A proposal I've made at Naval Biodynamics Laboratory is that we shouldn't do all our work on the big, expensive simulator. If this theory works, you can take a cheap, simple device, which allows an individual to get autonomic responses, and train him to learn to live with them. Then you put him back into the real world.

3.9 Recovery Rates

DR. DOBIE: With vestibular training and confidence building, you can recover intractably motion sick aircrew.

DR. MAY: What percent?

DR. DOBIE: Eighty-four percent, I think it was. Let me just add two points here. That was everybody. That included people who were sent to me and who afterwards said, "I came to you because I had to, but I have no intention of flying. I don't like flying. I didn't want to get into flying. My father is a three-star general, and he made me come back for this training. Now I've satisfied him, goodbye." Two of my failures were actually removed from, not only flying, but the Air Force, on psychiatric grounds, by a psychiatric panel.

I want to point out there are two parallel studies, one of which actually simulated, more or less, what I did. The other one was a totally different approach, but they were, I think, selective populations.

DR. KENNEDY: But really, the bottom line is your work, David Jones' work, Pat Cowings' work, all show positive effects from formal training as well as cognitive encouragement.

DR. DOBIE: That's right. The only difference is the success rate.

DR. KENNEDY: But they are all well above 50 percent.

DR. DOBIE: Sure.

DR. MAY: As psychologists, we learn early on that high level processes generalize broadly, whereas sensory things don't generalize real well. Adaptation is very specific.

3.10 Self-Scoring

DR. DOBIE: There are three elements I tried to build into actual training. One is that the individual scores himself. He tells me when he's better. I never ask him any questions when he gets out of the thing. I'm truly a sounding board. If he wants to talk, we'll talk for 50 minutes. Quite often, they get out of the thing and they're out the door in five seconds. Whatever they say, I record afterwards, after he's gone, verbatim. I never ask him anything--how bad do you feel or how well do you feel. I always take every opportunity to congratulate him on how well he's doing, but I also do one other thing. I usually get people to record their own success, as a method of reenforcement. I get them to start off saying, day one, so many minutes at such and such duration. Then they plot these things.

I've told them already in their initial interview, you're not going to make steady progress day to day. I use all kind of analogies like, if you're on a weight reduction program, you don't weigh yourself every hour or even every day. Once a week is probably soon enough, because otherwise you'll get depressed, because one day you're up and one day you're down. I say, it's the same with this ball game. What you're going to do is look at the trend, and I'm going to show you that you can respond as normally as anybody else. By getting them to draw it out for themselves, they say, yes, that's great. I always ignore the troughs and concentrate on the peaks.

3.11 Typical Time to Habituation

MR. CHAMBERS: What is the typical adaptation time, or the average?

DR. DOBIE: That's an interesting question I was going to come to. I had actually, in my group of 50 I had one guy who went up very steeply, very steeply. And at the end of the first week, he was saying, "Well, I have no problems. Let me go back." I believe, gut feeling, I should never release these people for treatment under maybe two weeks, initially, because I really don't know enough. I made an excuse to delay him. Would you believe on the Monday he had not made any progress for the first time. When I saw this fellow on Tuesday, he looked a bit despondent because his thing had gone very steeply and then flattened off. We sat and chatted away on, "I told you about the weight program. You're pleased with that. I would be..." That sort of thing. He said, "You know, I've just been thinking there's something I had forgotten to tell you. I used to get sick at school before I went into every examination."

Again, I acted as a sounding board. I never convinced him, because you don't want to finish up like a crutch or a hypnotist, where they will rely on you for their support; otherwise, you are then so critically involved in it that they'll break down. So he went to lunch and he came back after lunch and said, "You know, maybe I'm getting sick in the air because I'm so anxious, and I'm trying to do so well. Let me get back on the machine." He went back on the machine and he went straight up to the top again.

3.12 Success Stories

DR. DOBIE: At the end of the training they used to say to me, when did you want to see me again. I always made a great point--I even tried to force them into saying that if they didn't come up with it, so I could say to them, "I don't want to see you again. Why would I want to see you again? You say you feel fine now. That's great. If we meet for a beer sometime, I'll be delighted." I believe that was still a test of was I confident in them, so I always played it low-keyed again. I never heard from them. Then I wrote to them six years later. This guy had gone on to the Royal Navy on exchange, and he said, "You might be interested to know that not only do I not get airsick anymore, I never get seasick, either."

Another example, and it's the last one I'll mention. I had asked, "Are you 100 percent better or something, or whatever? How are you? If you're not fine, how do you estimate your present state." This guy said something like 83 percent or 87 percent. It was an oddball number. He said, "I believe that because I am the squadron aerobatic pilot, solo aerobatic pilot on Lightning. If I do more than three demonstrations a day, in the summer, near the sea where I have to wear an emergency suit, and I get overheated, I have, on occasion, felt slightly queasy. It doesn't bother me, of course, and I carry on," so he said, "I can't be 100 percent."

The reason I would like to use visual stimuli is I believe you could do that more cheaply than a vestibular gadget and you could, perhaps, do it for large numbers rather than just individuals.

3.13 Alternative Devices

DR. DUNLAP: In other words, you can have a cinerama where you can put a bunch of them.

DR. DOBIE: One wonders if you could do that. Certainly, it's very cheap. Anything will work that produces an autonomic response. I don't care where it comes from. You can walk them on down the road and get onto a fairground device, and that will give you the same feeling.

4. Questioning the Perceptual Conflict Theory

DR. DOBIE: There are a variety of reasons why people have these apparently severe responses. A lot of it may be due to their achievement level, therefore, their personality background. A lot of it may be due to whether or not they've had a bad experience in the past. I believe that from day one you are either sensitized or habituated according to your experiences.

MR. CHAMBERS: In this training, are you spreading out the tolerance band so that that same amount of cue difference is now within their acceptance or normal span?

DR. MAY: I think if you buy this, it calls into question the perceptual conflict hypothesis. It does not lead or elicit motion sickness. It's a period of disorientation, and if people aren't used to that, it makes them anxious, they get stressful, and that causes the sickness.

DR. DOBIE: Autonomic responses.

DR. MAY: You may even get to a point where with lots and lots of practice at this task, it doesn't even cause disorientation again. It may be an issue apart from motion sickness.

DR. BERBAUM: Isn't that a bit of an overstatement? Both of those things could be going on at the same time. It seems to me more what you're saying is that he's going to continue to have the symptoms that he had before. It's just that now he's going to be able to live with them. They may ultimately disappear by natural processes.

DR. DOBIE: That's right.

DR. DUNLAP: Let me suggest one scenario where that progression may not be true. I go out on a charter boat and I'm fishing and drinking beer and having a great time. All of a sudden, whoa! I didn't have anxiety. I didn't have fear. I didn't recall some episode. I was having a great time catching these fish, and unbeknownst to me, all of a sudden I got sick. Then when I have to start tending to the horizon and doing those things I can do to pull it back. But I didn't go through the progression you talked about, particularly the anxiety.

DR. KENNEDY: I think control of your gastrointestinal functions can be learned. I think you can do better at this after awhile. I think you can learn to inhibit some of these. I think that you can set up for yourself something else to focus on. There are a whole lot of techniques that can work, that can modify how you behave somewhere down the line, based on merely getting used to the stimulus and controlling your bodily functions. With repetition of conflict, another process begins to cut in. The reason why some people are sick and others are not may be due to individual differences in the perception of the magnitude of the conflict, and individual differences in the way that one recovers from conflict. I think the kind of thing you're talking about makes sense, because there's no question but that you're able to make big inroads on what happened. But I think the perception side is important as well.

DR. EBENHOLTZ: I wonder if you would consider something like clinical trials, where we might withhold the counseling type, reassurance type aspect of the treatment, and simply expose them to the apparatus.

DR. DOBIE: I had a problem here. I had a problem, because this system had worked. Now, the problem that many cardiologists have, in terms of the ethics of looking at perspective trials on current heart surgery. Do you withhold something which might mean that it won't work, so you're dealing with these guys' future, and you've only got a month. If you don't succeed at the end of the month, they're gone, and the system isn't going to bring them back again.

DR. EBENHOLTZ: It seems to me that there are really two very significant phases here; that is, I can very readily imagine individuals who react to those symptoms. They have motion sickness symptoms and they react to it in certain extreme ways, almost like establishing a phobia, and then you have to go through a desensitization procedure. On the other hand, there might be others who haven't yet gotten to that point, but who benefitted from the physical training.

DR. MAY: If I could get back to the perceptual conflict hypothesis for just a second. It really hasn't been tested very well, and we can test it. It's very easy to test. Walt (Chambers) can test it probably better than any of us. You can create horrible perceptual conflicts and look at the incidence of motion sickness, but that's not really been done systematically. Tom and I have one way, and down the road, we intend to do that.

DR. BERBAUM: The problem with your notion, as I see it, is that there aren't any instances of motion sickness that you can't explain in terms of the conflict theory of motion sickness, so you have a very difficult time getting your control.

DR. MAY: What do you mean? Let's put a chair in the middle of the drum and rotate them at exactly the same speed. Do people get sick? There's no perceptual conflict.

DR. BERBAUM: Yes, there is. You can suggest that the conflict comes about by an asynchrony in the neural responses of the modalities. Yes, and it's been done.

4.1 Quantifying the Conflict

DR. KENNEDY: The thing that I have pressed for, and I keep asking others for it because I can't figure out how to do it myself, is how do you quantify the magnitude of the conflict. Then I think we could say something about the assumption that more conflict is expected to result in more sickness. But we're left with making conflict an either/or proposition. In those cases where sickness occurs, I know very few where you cannot say that this is in conflict with that. The real problem for the conflict theory, in my opinion, is that no one has been able to quantify it.

5. The Necessary Interval Between Simulator and Aircraft Hops

DR. KENNEDY: Some simulators now carry restrictions. Do you have any feeling about the amount of time subsequent to simulator exposure that they're talking about, 12 hours, 24 hours before they fly in an airplane? Should they be permitted to drive? Is there any relationship between whether they experience symptoms or not, and whether one ought to enforce it for all or just for those with symptoms?

DR. DOBIE: It's obviously a problem that's exercised me, as you, Bob [Kennedy], for a long time, because of dealing with these people in the real world. I can't really answer your question. I can give you a number of instances that show you how I think about it. Firstly, I believe it is related to how long you keep them in a provocative environment, having responses. I believe that if you leave them with their responses for a long time, then generally, it takes longer for them to recover. But that's one of the experiments I have in mind to measure looking at responses.

The second thing is I always work at threshold, rather than further down the spectrum. People will argue this with me that you can't--how do people know how to reproduce threshold, and is there a threshold point, and so on and so forth, but I do that for two reasons. One is that I don't have any problems getting the guys coming back again, which I would do if I worked at, like at emesis, because obviously, you lose cooperation. Secondly, I define threshold to my subjects as something where their responses disappear within almost seconds of getting out of the drum, certainly minutes.

I know, for example, at Pensacola, when they put them in their devices for testing our sailors, they don't let them drive. I had one of my sailors complain bitterly. He had his new motorcycle down there, the weather was beautiful, and he wasn't allowed to use it. I think that's probably very sensible, because they were taking them to an extreme in a test situation. You know what I mean, Bob, in the various devices, under Mike Lentz's and Fred Guedry's guidance. But because I'm working at threshold at UNO, for example, in the drum, I let them drive. But what I do, without appearing to be taking a questionnaire afterwards and breaking my rules, I always casually chat to them, if they've said, I feel dizzy or rough. In the first two or three months, I take about three runs to find their threshold, and then after that I don't have a problem, because their symptoms disappear. Then I usually walk down to the car with them and keep them chatting longer than I otherwise would, if I think they're still feeling dizzy. So yes, I'm conscious of it, but I think it's almost not a problem if you work at early response.

DR. KENNEDY: How about for simulator sickness exposures?

DR. DOBIE: There, again, it's the same thing. If you let the guy get in there, and for the last two hours out of a four-hour run, he's been very sick and feeling rough, then you probably would have to keep him maybe 12 hours. That's why I think that we should try--well, that's the whole object of this working group is to try to avoid people getting so far, and at the same time, getting productive work out of the simulators.

DR. MAY: We have another case where one fellow, for one of our experiments, sat in a drum for ten minutes, came out and threw up all afternoon. He was worried about driving home. He came in the next day, and didn't feel too well. Then he entered into one of Tom's experiments, which asked him what his threshold was. It was like two minutes and 30 seconds. So in the previous one you might assume he would be sick. He had been sick for eight minutes. Maybe that's a recommendation you can make about simulator sickness is that they ought to get some information from these people about how they're feeling, because they obviously will put up with a lot of sickness.

DR. DOBIE: If you bite the bullet and go on living with this for a long time on that run, I think probably 12 hours is not a bad idea. But I avoid it by never letting people get like that. I don't get them to press a button every time because my gut feeling tells me I'm not going to get them to build their confidence.

MR. CHAMBERS: If they have to get this simulator time under their belt and that night, they've got a night operation out to the ship that they've been waiting to do in their helicopter, for so long--. What I'm saying is that one should give consideration to what do the guys present to doing something about treating them. You can do that quite quickly.

MR. CHAMBERS: Does that kind of program lead to a situation where you would have a volunteer program to take this, and its reward was they weren't grounded for so many hours after simulator training, and probably several other events?

DR. DOBIE: Yes, because there would be no need for it. As I say, I can tell you from my 50 individuals, they didn't have any sort of hang-ups about taking the training. They were quite proud of it.

6. Long-Term Effects and Activity for Readaptation

DR. KENNEDY: Sheldon Ebenholtz worked with lenses, prisms, and more things than that. You've done hundreds and hundreds and hundreds of perceptual modification. Have you got any posteffects? Do you have any sea stories that you would like to drop out? Like has anything ever happened four or five hours later?

DR. EBENHOLTZ: There are continuing effects, but it seems to me there's a way to undo those continuing effects. What I found in working with a number of different kinds of transformation is that you keep them in the dark you're sort of putting them on hold when you do that. You're permitting no further retraining in any of the oculomotor systems that may be implicated. Then the changes that were initiated by the transformation will stay, and the estimate we have is that they'll stay forever.

We haven't kept people sleeping there, but there is at least one study where people have slept and had the change measured the same day, and it was still there. So it seems to us that the reason it doesn't linger is that the transformation gets undone. When you take the prisms off, you're reexposing them. Now, that doesn't always happen, depending on the sophistication of the transformation; that is for a particular kind of oculomotor conflict, maybe you have to go to certain pains to make sure it gets undone, so to speak. So the answer would be that these things tend to get undone when our subjects walk around without the prisms on. As a rule, we have them do that for at least a half hour after prism exposure. There are a few studies in tilt adaptation where it looked virtually identical; that is, you had to undo it for the same amount of time that you were exposed.

DR. KENNEDY: Are there any capacitor like relationships where, under the right kind of circumstances, impoverished environment, day later, 48 hours later, 24 hours later, something pops up?

DR. EBENHOLTZ: In the transformations I've investigated, the subjects might be exposed to a half hour to an hour. I haven't caught any of those.

DR. DUNLAP: Have you gotten situations specific effects where--I don't know if you've run people on repeated measures, where you adapt them to a particular set of goggles, and they get to where they're pretty good with them, and then you give them the goggles without the lenses in them, do they then show the same kinds of adaptation--

DR. EBENHOLTZ: I've heard of that. A fellow named Kravits (phonetic), I think, was working with Wallach. I think he reported that kind of stuff. The closest I've come to that is in the vestibular system, retraining the VOR. There, we can get evidence of highly specific illusions, depending on the meridian in which they are trained, and even simultaneously in different directions.

DR. MAY: What I think Bill [Dunlap] was asking for was how can you objectify that so that others can do it.

DR. DOBIE: You can easily program the early confidence building counseling. But when you get to giving a a person experience and teaching him that he is capable of suppressing his responses in an increasingly longer duration exposure, if you allow him to go in and concentrate on looking for symptoms, and then aborting, you are really going the wrong route.

DR. MAY: But I don't see a problem at all with writing a program text to teach flight instructors how to handle their subjects in the earliest phases of simulator training. And in testing instructors to see whether they really do understand your methods or not.

DR. DOBIE: That can be done, yes. But I thought we were discussing a system whereby we really minimize the amount of personal supervision and that's what Bill [Dunlap] was really after, looking at a way that rather like Bob [Kennedy] talked about, sending a him down to the end of a hall with the umbrella and letting him train himself.

DR. DUNLAP: That would be nice, but it doesn't have to be.

DR. MAY: Let's make that distinction. It's certainly possible to set up a training program for flight instructors and teach your method.

DR. DOBIE: Yes.

DR. MAY: But it might be very difficult.

DR. DUNLAP: To do a self-help?

DR. MAY: To mechanize your method with a computer or whatever.

DR. DOBIE: And also you would lose the sort of sounding board reenforcement that I give. That can be taught to anybody. That isn't a problem. You really need somebody there.

DR. MAY: The bottom line is it will require interpersonal interactions.

DR. DOBIE: Yes, I believe so. But it doesn't have to be anybody with specially sophisticated training. You don't have to be a physician or a psychologist, or come from a particular discipline. I think you can teach someone to do it who has an interest and has enough confidence in handling people. And certainly the few times we have tried it, it has worked. So, it doesn't just need me or one person who has lived with it all his life or anything like that.

DR. DUNLAP: Let's go ahead and say what you would tell the person who is going to stand in for you to do in a programmed sort of way.

DR. DOBIE: It's essentially a confidence building program. A person essentially talks about motion sickness and the fact that it is a normal response because at the stage where he has got a bad history believes that somehow he is abnormal. You know, he thinks there's something wrong with him. It's essential to tackle that first counseling session in this abstract way. You are not talking about him. You are allowing him to convince himself by what you have said that, hey, if this happens to everybody I am not as strange as I thought I was. And I make sure that I have covered all the problems he's likely going to have. I think you can be sneaky about it if you want. You can find out exactly all the problems he has had. And pretend you don't know, and make sure you cover them, but you really don't need to. I thought of doing that, but you don't need to. You know the problem he has had. And you cover them in the original discussion. And you will see that he noticeably relaxes. He starts on the edge of the chair, and then gradually settles back a bit. I can now identify with all these other guys, and I thought I was on my own. And then at the end of the session as a throw away item, you check his documents, if he has documents. And you then just run through them quickly. The whole idea of demolish this horrible spector that he has been living with because you say, oh, yes, we have seen all this, everybody has this. It's normal, you know, throw it away. And then you reenforce it by some adaptive training, if you like, but I tend to stress two things.

Firstly, I don't care what equipment we use. I make that point because you then don't run into all the problems of the guy saying, but that isn't like my airplane or that isn't like my simulator or that isn't like the ship I am on. You avoid that. And that is a typical resistance you get if you do try to simulate something. So what I simply say is we can do it any which way you choose. But I am in a hurry, and you are in a hurry, and we haven't got time to mess around with airplanes. So, I have a little gadget around the corner which will do what I want. Because I am interested in his creating your personal yuk factor, and I don't care how I create it. And I will teach you to live with that, and show that you can suppress it. So, whenever you experience it, and whatever modality, doesn't bother me. And it won't bother you in the future because you know how to handle it because you have experienced it before, you have reduced it, and you have learned to live with it. And you can see by repeated practice that as days go by you will gradually get better and don't expect to get better sequentially on each trip. It ain't like that. But over a period of time when you plot out your duration of exposures, you will see that your symptoms are getting less or the duration is getting longer or both.

And then the day you tell me you are now satisfied that you really can handle these things is when the treatment is finished. There is no specific magic in rates of rotation or magic in durations or numbers of runs. It's when the guy has got his confidence. And it's absolutely critical that he make every decision. Otherwise you become a crutch that he leans on the whole time. The next time he has a problem he runs back to the therapist. And that has to be avoided at all costs. He must tell you everything. And to reinforce that, I don't measure anything negative. And I don't ask questions about how bad do you feel after every run because that is reenforcing the wrong thing. So, consequently, when he gets out of the stimulus environment, whatever you choose to use, I don't say anything. He leads. And he will get out and say, I felt a bit dizzy that time. You will say, well, I thought that was fantastic. Look what rate you were doing or look at the duration. You keep on stressing how well he was doing. The last thing you say to him is how sick were you.

So once you can get that into anybody's mind so that he learns to walk the tightrope, because I find that subjects are continually testing you in a way, looking to see if you will agree that they are not doing very well or looking to see if you will make any statement that suggests you were really only kidding them in the first instance and they really are individually different from everybody else. You have got to watch that like a hawk. But once a person understands that, I believe any intelligent person can run the program. There's no psychoanalysis in it or anything complex. It's just simple rule-of-thumb common sense. But don't make a mistake, otherwise you will set him back. You have to be wary because I believe they are testing you the whole time to see if you really believe what you are trying to suggest. So, in a nutshell, I think you could train a him that way. An instructor could be tested simply by my pretending to be a subject. Give him a few for instances, and then he gradually gets the message. In fact, he quickly gets the message if he sets his mind to it.

DR. DUNLAP: Do you push him to his limit every time.

DR. DOBIE: I don't do that for a number of reasons. One of which is because I think it's difficult, and you tend to overcook somebody. And then I think that sets them back. I think the time he spends out of the drum thinking about his improvements and what you are saying is more important than the time he spends in the drum or the chair or whatever device you are using. If he doesn't think about it, he doesn't make progress. So, what you then have to do is try to get them somehow to speak and maybe one day say the drum's unservicable, use anything you like. Now, you are here. You know, how are you getting on. And you don't start questioning them. But you start talking in such a way that you lead them into asking you questions, and then you act as a sounding board for their thoughts.

7. Can Dobie's Therapy Be Mechanized

DR. DUNLAP: I don't want this answered now, but I want you to think about it for awhile, and at a later session, try to get this into our record. That is, try to formulate a way that we can mechanize this thing. How could we formalize this so that the practitioner who does the treatment doesn't require extensive hands-on training. He can learn procedure in a systematic way, that covers all the details.

DR. DOBIE: A fair point. This is one of the reasons I'm going to visual stimuli.

8. Cognitive Responses to Autonomic System

DR. DOBIE: Let me make a point that Mike [McCauley] raised this morning and I haven't had a chance to pick up on it. He mentioned a point that he noticed in previous work that in some individuals appear to adapt or habituate during a say two-hour run and others don't. I think in that context what I am suggesting, and I will be interested to hear your comments on this, is I believe that people who have a strong anticipatory reaction to a motion environment fail to habituate in the way you have described because, firstly, they usually don't stay in there long enough. And secondly, their mind is so affected by this previous set, this anticipation, they go in saying I know I can do this.

DR. MCCAULEY: Let me contribute one other thing here. Getting away from the word fear a little bit. I would say that I observed in some subjects an enormous distaste for the whole motion sickness syndrome. And some of them in fact have claimed to never have been fully sick before. And as these horrible feelings start coming on, they do not like this one bit. And that's when I started to see people hyperventilate because it's a very noxious situation for them.

DR. DOBIE: I am the same way, which is why I stay at threshold. I don't want to get these guys in that situation.

DR. MCCAULEY: So for them it was not expectation; it was not a phobic thing about getting in the simulator to begin with. They don't know what frequency we were going to run them at. If we ran them over .5 Hertz, nobody got sick anyway. It's when all the beginnings of all this, the whole syndrome of feeling so horrible that some of these people would start to hyperventilate, and get really upset. It's kind of a cognitive or emotional response to the autonomic system.

CHAPTER VI

Discussion with Sheldon Ebenholtz, Ph.D.,
and Michael McCauley, Ph.D.
September 26, 1985 - Morning and Afternoon Sessions

1. Introduction To Ebenholtz's Work

DR. KENNEDY: Could you review historically what you work on and your experiences with these kinds of events?

DR. EBENHOLTZ: Current research activities are mainly in two areas. One entails various aspects of spatial orientations. I have just completed building a two axis rotator. In this kinetic mode we can examine real interactions between vision and vestibular modalities. By mounting visual displays on the shelf of this rotator, we can place an individual at pitch and roll angles, and record responses from them.

I have always been interested in spatial orientation. And I have completed a long series of studies on rod and frame phenomenon showing that the visual-vestibular interaction is a central aspect of it.

Another aspect of research that I spent some years at, and perhaps is most germane to this problem, stems from my interest in adaptation to various kinds of spatial transformations.

I started playing with Dove prisms many years ago, looking at the capability of organisms to adapt to a rotation around the line of sight while looking around or acting in other ways to their environment. I chose that because it looked like the most difficult transformation to understand. The other transformations that have been studied seemed to be capable of explanation in terms of oculomotor adaptations like the displacing prism that Dick Held worked with. And others, left-right reversals and so on, all seemed to give way to other interpretations. Now, as far as I could tell, no one has solved tilt adaptation. I don't think anyone yet knows what in the system is changing.

1.1 The Motion Sickness That Occurs In Adaptation Studies (Left-Right Reversal And Severe Tilt Produce Sickness)

DR. EBENHOLTZ: At any rate, when you investigate various forms of adaptation you immediately run into a subset of the motion sickness syndrome. It's usually milder and rarely does it produce emesis except in the case of left-right reversal. If you have a subject wear just a single dove prism, where you retain the left-right reversal as I did when I first started out, then you run into very severe motion sickness syndrome.

DR. KENNEDY: Do they vomit?

DR. EBENHOLTZ: Almost.

DR. MCCAULEY: Nausea.

DR. EBENHOLTZ: Nausea, for sure. So, left-right reversal is a sure and very simple way, you know, to investigate these symptoms should you want to produce it in a relatively easy, simple fashion.

We took to using a pair of dove prisms just to get rid of that so we could work with pure tilt, rotate one prism in front of the other, and then you get rid of it. Unless you increase a degree of tilt, and then you can again, you again increase the severity of the report of symptoms.

DR. KENNEDY: Is this while one is ambulatory?

DR. EBENHOLTZ: Yes.

DR. MCCAULEY: What period of time generally do you have them walking around in this condition?

DR. EBENHOLTZ: There are examples of 15-minute exposures on up to several hours.

1.2 Ebenholtz Theory Of Adaptation: Oculomotor Shifts

DR. EBENHOLTZ: So the background of direct interest then had to do with reversing the background. It had to do with developing theories of prism adaptation. I remained dissatisfied with the reafference theory that Dick Held built on Von Holst's theorizing. As far as I'm concerned, most of the reported adaptations can be accounted for in terms of oculomotor shifts that bring with them sustained changes in one's perception. Now, once I became convinced of that, that then led to the possible interpretation of what might mediate motion sickness syndromes when viewing simulators.

1.3 Specificity Of Adaptation (vs. Learning To Learn)

1.3a Multiple Transformations

DR. MAY: Shelly (Ebenholtz), if I am correct, you find these adaptation effects to be very specific. If you adapt somebody to left-right reversal and they finally get to a point where it doesn't bother them anymore. Then that adaptation is specific to left-right reversal. If you flip the prism so it was up-down reversal, they would have problems all over again.

DR. DUNLAP: Do you have "learning to learn," do you adapt faster to a stimulus condition after adapting to a different condition?

DR. EBENHOLTZ: I investigated the effect of joint adaptations. For example, we put a normal right angle prism at the end of a series of dove prisms. So, we had two transformations, a tilt transformation and a displacement transformation, and we examined the interaction effects that might occur when you look at each one separately, and then jointly. And it turns out that they are treated quite independently. Two transformations just proceed as if the other one wasn't there. And you get no difference compared with individual exposure to each one separately. So, as far as tilt and displacement are concerned, it looks as though you are adapting two completely independent underlying mechanisms.

1.3b Contingent Adaptation

DR. MAY: Do you see any contingent adaptation?

DR. EBENHOLTZ: I have never investigated contingent adaptation. I can't speak to that. I only know of Wallach's and Kravitz's work with the spectacles. And I was not too impressed with the magnitudes of that.

DR. MAY: Many people have run experiments trying to find cross-modality contingent aftereffects. Nobody has been able to do it. I have never been able to relate contingent aftereffects in any systematic way to the motion sickness problem.

DR. EBENHOLTZ: I would go to the vestibular system to generate these conditional effects because the vestibular nucleus seems to be a clearing house for several different modalities. I think that's where you have the greatest chance of success to trigger some of these flashback like occurrences in the laboratory.

1.4 Induced Myopia

DR. EBENHOLTZ: Let me add just for the record a second area of research that I have been involved in. That is related to the onset of myopia. So-called work myopia or school myopia, induced myopia or whatever term you prefer. That has to do with adaptation in the accommodation mechanism.

2. Individual Differences In Adaptability

DR. DOBIE: Did you find individual differences when you were using the left-right? How wide were the individual differences?

DR. EBENHOLTZ: Individual differences permeate this area of research.

DR. KENNEDY: There are clearly high adapters and low adapters.

DR. EBENHOLTZ: Yes.

DR. MCCAULEY: Do they go across the different types of adaptation?

DR. EBENHOLTZ: Now you are asking a systematic question.

DR. MCCAULEY: Sorry.

DR. EBENHOLTZ: I have never made systematic comparisons about the relevant frequencies across different types of transformations. I don't think anyone has. But it is always there. No matter what transformation you pick there are going to be people who will show tremendous adaptation in a short period of time, and others who will show very little adaptation in long periods of time.

3. The Conditions That Produce Performance Adaptation Also Lead To Motion Sickness

DR. MAY: Considering these individual differences, how do you think adaptation works?

DR. EBENHOLTZ: I have modeled the systems that I thought were underlying the adaptation phenomenon. These systems are the convergent system, the vestibular oculo-response, and the accommodation system. That, in turn, leads you to consider the pursuit system and the optokinetic system. You have to add VOR loops and interactions with pursuit and optokinetic systems.

MR. CHAMBERS: These adaptations are performance adaptations. They are not motion sickness adaptations; correct?

DR. EBENHOLTZ: When you look at it from the point of view of the underlying oculomotor system, you find that the identical antecedent condition that produce adaptation also leads to the motion sickness syndrome. They are identical. If you want to produce one, you've got to be ready to treat the other.

DR. KENNEDY: And when you monitor the adaptation process the symptomatology disappears as the performance is modified.

DR. EBENHOLTZ: And you take the prisms off, you go through it again. Exactly.

4. Transfer Of Adaptation Across Stimulus Conditions (Kennedy's Transfer of *Perceptual Training [TOPT] Experiment* and VOR)

DR. KENNEDY: You said that the adaptation as a general improvement does not appear to go from one to another stimulus condition. What are the characteristics of the stimulus conditions where transfer is likely?

DR. EBENHOLTZ: I don't think I can answer the transfer-of-training question. There are a few studies of interocular transfer.

DR. DUNLAP: Why do you get the reactions you get in the TOPT study? Bob (Kennedy) can you describe it?

DR. KENNEDY: Ten subjects were spun ten times a day for four days by themselves. So they were self-propelled at about 20 to 30 RPMs each trial for a minute, after which they were stopped and they raised their heads. The postadaptation effect, the so-called Purkinjian effect, produces a Coriolis stimulus resulting in dizziness and ataxia. Ataxia and dizziness were measured, scaled over the ten trials each day. Both decreased with trials each day. By the fourth day most of the dizziness had disappeared. On the fifth day, these ten subjects were put into an optokinetic drum, and made 16 head movements in an AB BA design. The magnitude of the pseudo Coriolis effect in the drum was measured, and was substantially less in this group than in a control group who had no prior exposure to turning. So the perceptual learning involving a provocative self-propelled vestibular stimulus has transferred to a situation in which the vestibular stimulus is indirect or oblique. This second stimulus, of course, also comes through the vestibular nuclei; it is a visual optokinetic visual stimulus. This kind of transfer of training may have relevance for simulator sickness.

DR. EBENHOLTZ: I believe there is some research data showing a relationship between optokinetic response and gain of VOR.

DR. MAY: Can you really conclude that it is transfer from the vestibular system to the visual system considering that they had their eyes open while they were spinning?

DR. KENNEDY: Are you suggesting that they may have an optokinetic adaptation in both cases?

DR. MAY: Yes. Maybe you should just do the study over with eyes closed.

5. Contingent Adaptation, Incremental Exposure, Readaptation

DR. BERBAUM: Is it possible to reduce symptoms experienced in flight simulators either by adapting within the simulator or by pretraining on another device? Are there hazards? Also, could you address the question of contingent adaptation. I don't think that anyone would argue that it exists. Many of us put on and take off eyeglasses without ill effects. Some people have three or four pairs. Adjustments must occur for this to be possible.

DR. EBENHOLTZ: There are two responses. First, you can't doubt the fact that people do profit from training. There is plenty of evidence for that. The more experience you have the less likely you are to express symptoms. On the other hand, I would love to have a good laboratory demonstration of changes in the direction of the VOR triggered by different pairs of glasses. I just don't have that available.

DR. KENNEDY: The point you made about our TOPT data is that perhaps what you have learned is how to inhibit eye movements. If you could inhibit them with a vestibular stimulus, and transfer that to a visual stimulus, you still have transfer of something from two stimuli which makes it useful for simulator sickness.

DR. MCCAULEY: Another way to look at it is the incremental exposure idea. That's the same kind of thing by a different term as I see it. If you just want your exposure duration the first few times in the simulator and sneak up on it, I think in the vast majority of cases you're going to solve the problem that way. I am talking about perceptual adaptation to specific kinds of visual and vestibular cues.

DR. BERBAUM: If you adapt a person to a simulator you need to ask whether this generates symptoms when he gets into a real aircraft.

DR. DUNLAP: Some of the things that Shelly (Ebenholtz) said about the specificity of the adaptation reminds me of something else that Miller Reschke said. What he said was that, if you spin a person in the spinning chair with the head movements until they get really disoriented, and feel bad and sick, and so forth, he says the best way to put a stop to that is put them back in the chair, spin them in the opposite direction, and you unwind the thing.

DR. EBENHOLTZ: Precisely, yes.

DR. DUNLAP: If you were in the airplane with the vection feelings of going forward, maybe we could back them back up. That's maybe a little farfetched.

6. Definition Of Adaptation

DR. MCCAULEY: When I was in school, people were talking about adaptation as in dark adaptation which took 45 minutes. I talked a few years later to people who were studying the first 100 milliseconds of adaptation occurring at the retina. Another person was looking at dark adaptation over a period of about four days where cells are actually sloughed off. So, here we have physical, anatomical changes that occur over a period of days. I have a little problem believing that the same phenomenon that we want to call adaptation applies from the first 50 milliseconds through four days.

DR. EBENHOLTZ: It is only at a global level that you can give, I think, an overall definition of adaptation in terms of "a lowering of your sensitivity to the distorting stimulus." I think that this definition might apply to virtually all kinds of adaptation. The salience somehow diminishes until it's eventually not even part of your awareness. But once you get into the underlying mechanisms, then you've got a whole world of differences.

DR. MCCAULEY: We are looking for the adaptive mechanism. I would think there may be several of them going across these different stages or time constants. We may have some retinal level adaptations. We may have some things going on over months.

DR. KENNEDY: I think that the operational definitions offered by Dodge in 1909 on human variability implied that anything that has fatigue associated with it; that is, if the input or output pathway is not capable of carrying a stimulus, doesn't qualify as adaptation. Any local structural change doesn't qualify. In almost all cases we are not talking about a local change but rather changes in the central nervous system and in how we perceive or respond to things. Even a vestibular oculo-reflex would not occur without an extra synapse in the central nervous system. Would you agree with that?

DR. EBENHOLTZ: Absolutely. That's the big news in VOR - that it wasn't hard wired after all.

DR. KENNEDY: So you've got to rattle around in the central nervous system a little bit in order to discover what produces simulator sickness.

DR. EBENHOLTZ: There was a series of studies that I performed working with pairs of dove prisms that were run with a clock motor attached to them so that the subject walked up and down a long hallway. I wanted to go below threshold so that at any one time the change in perception was negligible or not even present. So, I worked at a range of input velocities. Subjects barely noticed the tilt until about seven or eight degrees, and some didn't notice the tilt until 10 or 12 degrees. This is looking at a hallway, long hallway, about 80 feet long. Now, you can drive adaptation up this way, and if you reverse it you can drive it back down again. One of the interesting things about this is that it's not the perceptual change. There are people here who look at the hallway and don't see anything wrong with it. It's just a nice upright hallway. They are not experiencing a change in perception, but they are responding to an input signal that is changing. The one point about this is that perception flows out of these inputs to the nervous system and that's why I am reticent to deal with perceptions as though it was the cause of the illusions or the cause of the motion sickness. I rather see it as occurring along with the motion sickness for very much the same reasons.

7. Avoiding Sickness - Actual Pilot Behavior, Adaptation Is The Cure

MR. CHAMBERS: I share Tom's [Dobie] concern about a person not having experience. Just like the high altitude chamber training so the individual can find what his onset symptoms are for oxygen deprivation; maybe some form of motion sickness needs to be brought to the onset state at least so he recognizes it. And then he needs to know that he needs to fly something different or fly the pattern differently from that point on, although there are time constraints associated with this that sometimes you can't turn around readily.

DR. DUNLAP: If it gets to be too bad how can the simulator pilot get out of the situation? And I would like to know what is currently the accepted thing. I mean if you start feeling real bad in a simulator can you say, hey, I want out. Or are you bound by the program that you must stay in there? And the second question I want to ask is, if you insert a mechanism for termination escape or at least timeout, will that so adversely impact the training that it wouldn't be workable?

MR. CHAMBERS: You were doing field observations.

DR. KENNEDY: Well, I think they probably do pretty much what you say right now. There is a pilot, two pilots, one instructor. Let's assume that the person who is flying the airplane is not feeling well. He will do one of the following. He will go on his gauges, he will stop doing what he is doing, he will tell the instructor pilot he is feeling uncomfortable, he will tough it out. All those things happen. He will say maybe I ought to get in the other seat. I think I would like to take a break, let's have a cup of coffee. Whatever all those are, the co-pilot has less involvement because he typically is not on the system.

DR. DUNLAP: Tom [Dobie] is telling us he shouldn't do that because he is conditioning the very negative things to the whole situation.

DR. KENNEDY: They tend not to persist doing whatever it is that they are doing that is making them feel bad. They do something to lower it.

DR. MCCAULEY: Wouldn't you say, Bob, that the most common thing is that when that student comes back the third or fourth time it goes away?

DR. KENNEDY: I would say that the first thing is he may not know exactly what it is that is doing it to him. If he is smart enough to know (either because of inference, or his instructor pilot, or someone else may tell him) he will tend to avoid it. But, of course, due to the adaptation process, the second, third, and fourth time it is less. I would be surprised if whatever the incidence of simulator sickness may be on a given hop for an early exposure it may follow a very, very abrupt learning curve. Thus, if 70 percent were sick on one, 20 percent to 30 percent might occur on two, and so on down to about 0 percent by four or five, so that if the numbers are true, 90 percent of the problem is in 20 percent of the people. You might want to say it's almost exclusively on the first couple of three hops. Also, I don't believe that the 30% who don't get sick on the first hop ever have a problem on 2-4. So some number of people are immune more or less.

8. Contingent Adaptation And Danger In The Aircraft Following Simulation - McCauley's View

DR. MCCAULEY: I think that the main problem may be that you're dangerous in the aircraft when you adapt to the simulator. I don't know that. I don't think anyone knows that. But to me that is the most important question. More so than taking these 20 percent of the guys and instead of them having the symptoms over their first six hops in the simulator, we are going to back it off to only the first two.

DR. KENNEDY: Most of our human engineering mistakes are adapted to, and from an economic standpoint, that's invariably the cheaper way to deal with bad design. This approach is aided by the "can do" attitude of aviators -- the aviator is infinitely flexible; put it where you want it, and I will fly it out. (But it's not a substitute for good design.) So is adaptation a viable approach? Can we adapt to environments simultaneously? Do we get into the problem of safety of flight?

DR. MCCAULEY: My guess would be that over the long run they will be able to achieve adaptation to both environments. They will perform just fine in both environments. But my guess would be that there is a period in the beginning when they are dangerous in the aircraft because of adaptation they are acquiring in the simulator.

MR. CHAMBERS: There is no evidence of that.

DR. MCCAULEY: That is pure guesswork on my part.

DR. KENNEDY: Except for some occasional reports that we keep, you know, repeating to ourselves about pilots who said, "I felt high, I couldn't land. I felt like I was in the simulator."

DR. BERBAUM: One way to program things to avoid that would be to train on both the simulator and the aircraft at the same time, and to keep those situations as distinct as possible so as to develop simultaneous adaptations to the two situations.

DR. MCCAULEY: I think that would be a good approach. And also I think it's important to inform these people.

DR. DOBIE: You really are not talking about motion sickness anymore. What you are talking about is a wise way to train people in a simulator.

DR. MCCAULEY: No. I'm talking about adapting to the sources of motion sickness in the simulator.

DR. BERBAUM: Such as temporal lag.

DR. MCCAULEY: Visual distortions, temporal lags, and those things we believe cause motion sickness in the simulator. Particularly in the experienced aviator. They are the ones, the evidence indicates, who have more problems.

DR. DUNLAP: A simple example might be if you are simulating a helicopter you may learn to hold your head real steady because if you move it you get pseudo Coriolis; you move it and you get out of the design eye, and it's really better for the person to fly the helicopter in the real world looking around, things like that. But you adapt to avoid getting sick in the simulator.

DR. KENNEDY: You adapt behaviorally.

DR. MCCAULEY: And later that afternoon you go out and fly the aircraft--

DR. DUNLAP: And hold your head stiff and it's not good for you.

MR. CHAMBERS: Aren't there similar concerns in going from one aircraft to *a different aircraft?*

DR. MCCAULEY: Yes.

DR. DOBIE: I was flying Vampire fighters, little jet airplanes, where you land your rear end is about a foot off the ground. And then in the afternoon I climbed into a four engine piston airplane where you are higher than this house. But when you are coming in to land it all fits. It all seems right. I mean, you never fly into the ground.

DR. MCCAULEY: Especially after awhile.

DR. DOBIE: I am talking about your first trip.

DR. MCCAULEY: I would like to measure it. I bet you are a little lower on the big aircraft.

DR. KENNEDY: And I bet you taxi faster in the four engine piston.

DR. DOBIE: Yes, I suppose. But again, a lot of it is this sort of practice of having a lot of, you know, getting used to a lot of airplanes. You don't have a set.

9. Control Theory Of Adaptation - Ebenholtz's View

DR. MCCAULEY: Does the perceptual adaptation in the simulator keep you from getting sick?

DR. EBENHOLTZ: There is an approach that I think captures a lot of what is going on here. But it does so from a theoretical orientation about control systems. The theory has to do with relationship among certain portions of the control loops, certain portions of the feedback system are assumed to underly the optokinetic system, the pursuit system, the VOR, convergence, and accommodation. Modeling adaptation at the level of the feedback control loop is very simple. It is simply a feed-forward signal that exists in all of these loops that gradually changes to control either the trajectory or the steady states of the eye in question. If we are talking about the vergence system then we are talking about the development of a change in muscle tonus.

By the way, one of the major jobs of the vestibular system through the vestibular cerebellum is to adjust muscle tonus. So we can walk around on the moon after awhile or walk around here with a heavy gravitational load. So that job is being done for us. Now, when you apply that reasoning to the oculomotor systems you come out with some perfectly neat examples of just how this is being done. Imagine that you have triggered a feedback error correction signal because there was an error to correct to begin with. Let's say you put your eye on a target or your eyes verge in such a way that you eliminate the disparity that would otherwise be present. If you have to keep doing that a number of things will happen. If you continually force the system to cope with an error, then you begin to get what the optometrists call asthenopia. Anyone that has a problem in accommodation right, and doesn't get it corrected, begins to get conflict between convergence and accommodation. Then you begin to get reports of that headache, feel pain around here [indicating around the face], I get a neck ache, and I also begin to get nauseous, and so on and so forth. You get a very nice subset of the motion sickness syndrome under asthenopia.

Okay. If you keep that loop open, you are going to get sick. But if you keep the loop open you are also going to force an adaptive response, if it's within certain physiologic range of the system. The adaptive response will occur from a subloop that looks at these signals as they are coming off of the feedback correcting path. It looks at the magnitude and direction required and begins to adjust the muscle tonus. And, in the case of convergence, what it will adjust your vergence position so that you minimize, if not totally eliminate, the error. It is a second way of eliminating error, but without continuing to utilize the major feedback error path. To put it slightly differently, the two pathways have a synergistic or symbiotic relationship. You can't get change in the system unless there is an error to cope with to begin with. But when you have an error to cope with in the system, you trigger another part of the system that eliminates the need for further error correction.

Now, that is the essence of the model. I can lay it out in more detail with respect to the VOR, the pursuit system, and optokinetic system, but the essence of it is that there is a separate part of the system that changes the muscle tonus or changes the dynamics of the system.

In the case of a pursuit system, for example, some people construe this as the anticipator in the system. You are simply building a little model so that you can relax the error correcting system and let the thing go automatically. And by the way, it also has a conscious aspect to it, because once the muscle tonus is adjusted in its dynamic and static states, once it is adjusted, you can relax. You no longer have to direct the system. The system is taking care of itself.

9.1 Set Point Models

DR. EBENHOLTZ: Now, the adaptive nature of this, in the systems that I have examined, turns out to be associated with a set-point model, a relatively common set-point model insofar as adaptive control systems are concerned. These turn out to be very parsimonious models because all you have to do is change the parameters that govern the set point, and you can change the values of the entire system associated with it. And that turns out to be quite predictive of perceptual states including illusions, illusions of all sorts, lovely illusions that occur in simulators. As soon as you change certain of the levels of muscle tonus or, for example, if you change the direction of the VOR, then in order to maintain fixation on a target you have to issue countervailing stimulation to counter the change that the VOR instituted as a functional result. I don't know if I am making sense. But the idea is that you can capture all the illusions that you experience simply by recognizing that one oculomotor system is attempting to carry out what is functional for it in light of a changed set of parameters in other oculomotor systems.

So in the case of illusions, like everyday illusions like following the moon, when you look at the moon and you are walking along, and the moon is following you, can be construed in terms of the pursuit system compensating for an optokinetic stimulus that wants to pull the eye with it. You know, if you look at the moon above bushes or treetops you have a very nice optokinetic stimulus that is doing its thing, which is to pull the eye with it. So you can retain gaze stability. But if you insist on looking at the moon, you have to issue a pursuit signal to counter that. That's what you read out and that's what produces your illusion. Now, I give you this example because you can go through the exercise, and I think account for all of the illusions that occur in a simulator.

9.2 The Possibility Of Contingent Adaptation

DR. BERBAUM: According to your model what kind of contingent adaptations occur?

DR. EBENHOLTZ: The model doesn't say anything about contingent adaptation. I remain skeptical about it. I would rather think that, for example, the vestibular system is responding and triggering these adaptations. I rather think that when you get into a real airplane that you begin to make different types of movements and that triggers the responses associated with that.

10. Headaches And Visual Cues

DR. DUNLAP: What about the ubiquity of these headaches? Are they more tied to visually based sickness?

DR. KENNEDY: Yes.

DR. DUNLAP: And less tied to ship based sickness or aircraft based sickness? Is it more tied to the visually induced malaise than to the vestibularly induced malaise?

DR. KENNEDY: Headache is something that exists in all forms of motion sickness, but it is stronger in the visual ones. I think other cerebral symptoms are more prevalent in the visually induced ones.

DR. MCCAULEY: Flashbacks?

DR. KENNEDY: Yes.

DR. DOBIE: In the drum, if you jack up the speed from 10 RPM to 15 RPM, you get a lot more headache responses, and people will say it is because they find this blurring very uncomfortable, because it's going so fast they can't fixate.

DR. MAY: It's also too fast for you to get really synchronized.

DR. DOBIE: Yes, that's what I mean, and they classically describe that.

DR. DUNLAP: Does anybody know what makes your head hurt?

DR. EBENHOLTZ: Muscles.

DR. DUNLAP: Which ones?

DR. EBENHOLTZ: Oculomotor system; you've got 12 muscles between the two eyes, and two more intraocular.

DR. KENNEDY: They're certainly the least fatigable of all the muscles in the body for sure. They are the biggest in terms of the amount of mass they are supposed to overcome. They have the best mechanical advantage. They are the fastest. But they certainly work harder.

DR. MCCAULEY: In our motion generator, which I view as almost entirely a vestibular driver, subjects had nothing to look at in a closed cabin. We literally had lots of nausea, lots of vomiting, and on occasion we would get some who said that they had a headache, but it was relatively rare compared to what I have heard in simulators where it is more visual.

DR. DUNLAP: The astronauts don't report these headaches. They don't report anything basically, but what they find when they go through the medicine cabinet after they get back is that all the aspirin are gone.

DR. KENNEDY: And labryinthine-defective persons, when exposed to the same environment that produce motion sickness in others, report headaches.

DR. BERBAUM: One thing you seem to be saying is that if we set up an optical system that decouples accommodation and convergence we are going to produce headaches.

DR. EBENHOLTZ: That's correct.

DR. KENNEDY: If you become pale does that mean your eye muscles have less blood too?

DR. DOBIE: That may well be, that's right. They may well be just ischemic.

DR. KENNEDY: So headache is a function of not enough blood to the eye muscle.

DR. DOBIE: Could well be. I think it's quite possible.

DR. MCCAULEY: You might want to ask those subjects who have a lot more pallor than others whether they also report headaches.

DR. DOBIE: There is another thing that sounds a bit ridiculous and a bit farfetched, but in fact, in a simulator as distinct from an airplane, you are doing less legwork, so, you are getting diminished venous return, so, you are getting diminished cardiac output. It is like sitting in an airplane as a passenger; one of the reasons people get tired and a bit headachy is because they're not moving their legs. So, they got no venous return. You get foot swell; classically they can't get their shoes on again at the end of the flight. And you can't push blood out that doesn't come back.

11. Causes Of Simulator Sickness: Conflict Between Optokinetic Stimulus And VOR

DR. EBENHOLTZ: Let me just say a word or two about what I think the dominant causes of mischief are in the simulator. One is head movement. Everyone recognizes that the head movement is critical, and all airline supporting personnel are taught don't move your head during banks and so on to lower the incidence of motion sickness. The reason head movement is such a critical factor is because of its relationship to the vestibulo-ocular response. Now that's not the only kind of reflex that is involved. You also have vestibulocholic responses that are built in. So that when you stimulate that vestibular system you also want to make corrective head movements, righting head movements and so on. So, to a certain extent, those may be playing a role as well. That is, if you inhibit those then you are also triggering a feedback loop, and you may be triggering some other changes in the system that we are not even measuring. Spinal reflexes, for example, righting reflexes may be altered, and very few people are measuring those.

If you move your head and trigger a normal vestibular ocular response, then it wants to be compensatory so the reflex is to move the eye in the opposite direction, and in a more or less equivalent magnitude depending upon your individual gain. Now here's an important parameter here. Not everyone has a high gain. Some people have a low VOR gain, 0.5, 0.6 gain in the dark. So that the VOR is not doing the total job of compensation. Okay. Other people have very high gain where it looks like the whole job of compensation is being done by the VOR. They don't need any assist. Now normally the assist comes from an optokinetic pattern, so it carries on and contributes the other 10 or 20 percent so that your eye can finally stay fixed on target.

DR. KENNEDY: Would you say the high gain would be more or less susceptible to simulator or space sickness?

DR. EBENHOLTZ: I have to trace out the other part of it. It is not just high or low gain that is going to produce the problem. It is where that optokinetic stimulus is directing the eye, because that is the source of conflict from my point of view. Not at the perceptual level, but between two signals. Each of which is requiring the eye to move in different directions and perhaps at different magnitudes. And, consequently, in essence you have two vectors that the same eye has to decide between. And that usually means a vector resolution. Now a vector resolution means an error because if you resolve it you are not going to be where the target is. The target is calling for one thing; your VOR is calling for another thing. If you take the vector solution, you must have an error in the system and that's where I think the cause of motion sickness is.

DR. MCCAULEY: So that's an explanation of sensory conflict?

DR. EBENHOLTZ: At the level of the oculomotor system.

12. Walt Chambers' Invitation to Propose Experiments for Eye- and Head-Tracking Displays

MR. CHAMBERS: Before getting on to another topic area, since we were talking about experiments involving opportunities with systems that have eye and head tracking, I want to invite all the participants to propose experiments. Next year there will be four systems under evaluation that involve head and eye tracking and simulators. They are in research laboratory environments; the mission is to look for any adverse effects of the head/eye-tracking system being used in a simulator. So there is an opportunity to piggyback any experiments that you might want to propose. I invite anyone interested in proposing an experiment to help resolve these issues to do so. You could work through me if you want. Our lab is involved with controlling two of the evaluations, and the HRL has the other two systems. But we are on a committee that is coordinating evaluation of these.

DR. MCCAULEY: We will have one at Ames Research Center too.

MR. CHAMBERS: Okay. Just for awareness of sensitivity of eye measurements, most of these systems have filters on the eye trackers that purposefully induce a dead band so the tracker does not try to track small dithers inside one or two degrees. And so you won't get that kind of fine refinement in the data that is coming out of it. Otherwise, you would have the display dancing around.

DR. DUNLAP: But you can tap the eye sensor before the filter so you can collect that as part of the data base?

MR. CHAMBERS: It would be difficult, and it would cost money to add that in. That won't be readily available in the main computer. And that is pretty much true on all those systems.

DR. MAY: You could be three degrees off to where you think the eye is looking?

MR. CHAMBERS: Right. But you would have update rates of 60 Hertz on position. There have been two evaluations conducted on the like device, and we have reports on those. If you want to pass your name to Bob (Kennedy), I will send you copies of those. They were very preliminary evaluations; just looking for gross effects. The basic finding so far is that they don't make people sick any more so than other simulator visual systems. Timing on this is near -- they're going to be starting to decide in the November time frame as to the content of the upcoming evaluations. Some of them are starting shortly after the first of the year.

DR. MAY: Are these area-of-interest displays?

MR. CHAMBERS: These are eye-tracked area-of-interest displays. Some of them are totally helmet mounted, head mounted, some of them are projected on walls and are eye tracked. But you have eye- and head-tracking information on all of this.

DR. DUNLAP: When you do it, you put in a background, but you simply increase the intensity of the area of interest so it overlays the background so it washes out what would have been there, or do you have a donut-shaped background?

MR. CHAMBERS: Most of the systems now cut holes in the background where the area of interest--

DR. DUNLAP: Cut holes?

MR. CHAMBERS: It's better than washing it out. It's substituted for it.

DR. DUNLAP: Because we can get a lot of interesting vection questions answered with holes.

MR. CHAMBERS: Well, all of them have the option of not putting any information in the area of interest and that the size of that typically at least on some of them can be varied from 18 degrees to 30 degrees, the size of the hole. The maximum field of view of the background scene is usually around 120 degrees. So there is some area that is not filled in the periphery.

DR. EBENHOLTZ: What determines the nature of the pattern?

MR. CHAMBERS: They are all driven by computer graphic CIG systems. And some have more scene content capability than others.

DR. KENNEDY: Where are the four?

MR. CHAMBERS: There's one at Orlando at VTRS, and one at Binghamtom; there will be two at HRL at Williams.

DR. MCCAULEY: And one at NASA Ames Research Center, but that will be about a year from now. A little more.

DR. KENNEDY: But the people who have been here ought to be alerted to those five, and if they have any interest to communicate with you. Who would be the person in Phoenix at Williams?

MR. CHAMBERS: Well, Tom Longridge has left, and I have forgotten who has taken his place.

DR. KENNEDY: Elizabeth Martin.

MR. CHAMBERS: She is still there.

DR. KENNEDY: Elizabeth Martin at Williams, and Mike McCauley at Monterey Systems. And then Walt Chambers at the Navy's Visual Technology Research Center in Orlando.

MR. CHAMBERS: There is a tri-service committee that will be meeting at the ITEC Conference in mid-November.

DR. KENNEDY: That will be held in Orlando?

MR. CHAMBERS: Yes, in Orlando. All those outfits will be represented, and one of the principal topics is the evaluation of IM head-tracking systems.

MR. CHAMBERS: You should think of these as like the space shuttle and piggybacking the experiments onto something because these programs are in place. They're going to happen, and they are looking for good evaluation issues.

13. Retinal Slip

DR. KENNEDY: I am not the best spokesman, but my understanding is that one of the concepts for space adaptation syndrome or space motion sickness is that it is due to retinal slip, and some of the things that were studied in the last series of shuttle flights dealt with that.

DR. EBENHOLTZ: Well, I am very interested to hear that because that seems to be rather precisely what I have been advocating, though not the retinal slip as such. It is the fact that slip represents an error forcing the rest of the system to either adapt or get sick or both.

DR. KENNEDY: Retinal slip is directly related to visually coupled systems.

DR. EBENHOLTZ: Just as retinal slip is the obvious way to characterize an error in the oculomotor systems, there are other error signals that don't have retinal slip. All the other signals that come from the excitation of the vestibular cerebellum--

DR. DUNLAP: You are using a word I don't understand, retinal slip?

DR. KENNEDY: The object is not being held on the eye. The argument here for stroboscopic and no motion sickness is that there is no retinal slip because you click it on the eye--

DR. EBENHOLTZ: Of course, we know it's really a motion signal that is critical and you don't actually have to have the slip there. But because you do it through stroboscopic movement so in fact there is no real moving image across the retina.

14. Ebenholtz's Approach - Compare Acceleration Of The Head And Optokinetic Pattern

DR. EBENHOLTZ: The essence of my approach is very specific analysis of the direction and velocity, acceleration characteristics of the head because that in turn is predictive of the VOR. Then very specific analysis of the optokinetic pattern that you are confronting the observer with. And by the way, there are also optostatic patterns that we shouldn't dismiss. Static patterns control vergence; the more patterns you have, the greater the fusional demand. To a certain extent we're beginning to believe that density of pattern may also have an effect on the accommodative system itself. In other words, these things are liable to be simple gain controllers. The greater the density of the patterns then the greater the signal strength. So, that there are optostatic as well as optokinetic patterns that influence different oculomotor systems.

If you take account then of the demands that these systems make, and you also take account of the demands of the tasks where you have volitionally directed eye movements that have to operate in addition to those that are reflex operating, then you have all the ingredients of the recipe. You can then use that to deduce illusions based upon oculomotor pursuit for example. And you can also get estimates of the magnitude of error by looking at the amount of time you spend in such a situation, and at the amplitude of the resulting vector that emerges when you compare the several demands on the system. I think there is a recipe there for actually deriving a numerical estimate of the amount of demand on the system.

Now, whether one wants to go through the trouble of actually doing that, it means recording, probably digitizing, the flow pattern. It means getting a simultaneous record of the acceleration present on the canals. So that you can then calculate the direction of the VOR, and it means then comparing the two. Which is no small effort. But I think in principle it can be done.

14.1 How To Characterize Optokinetic Flow; Eyepoint?

DR. BERBAUM: If you were dealing with a simulator which projected a perspective display on a wide field for a particular design eye, could you use some readout of the original parameters for the apparent position of the observer's eyepoint movement through the depicted scene as your measure of the flow pattern?

DR. EBENHOLTZ: Well, it depends on the purposes that you have in mind. You've got to know what is going on in the periphery as well. And you have to have a measure of the flow pattern, the density of the pattern, and the velocity of that pattern to know how much of a demand it is making on the system. Just to get a foothold in to this problem, the minimum that we need is to take some measures of where the head is when a person is sitting in his simulator.

14.2 Digression - Simulator Design Eyes That Move With The Head

DR. DUNLAP: May I interrupt for just a second? This concept of a design eye, that is the stimulus is designed for eyes positioned at a certain point in space, and, of course, they may not stay there. But nowadays you have recordings by way of sensors on helmets of where the head is. Can't the computer recompute the scene based on the new location of the actual head?

MR. CHAMBERS: Yes.

DR. DUNLAP: Why does a design eye have to stay in one place where you can move out of it? Why can't the design eye follow the eye?

DR. MAY: Move with the head.

DR. DUNLAP: Yes, if you move over here, you can compute the image for the eyes over here rather than over here.

MR. CHAMBERS: That is correct. That is currently implemented in the Links Edit System. There are systems on which we ran two evaluations, and although the image is only ten feet on the wall in front of you, if you do this with your head, the image moves as if it were infinity.

DR. DUNLAP: So, that means that this question of whether there is an important contribution to simulator sickness because of a fixed design eye can easily be answered. You can either have it fixed or not fixed.

DR. MAY: It means something different if it is fixed. You really aren't imparting a perception that the scene is at infinity.

MR. CHAMBERS: As far as head motion. Your eye convergence will be at ten feet, and you cannot in that situation get anything in the image to appear as if it's closer. I guess you can, if you move it across the image.

DR. BERBAUM: You can. They set up where your position is -- say behind the pole -- and as you move your head you can look around you. It computes perspective around it. And, you know, again there is no stereo in the sense that it's a 2-D image and all that. So, here's a conflict of a different kind, if you will.

14.3 How To Measure Optokinetic Flow: Relative To VOR, Approximation

DR. BERBAUM: How then are you going to quantify a flow pattern?

DR. EBENHOLTZ: In terms of its velocity and direction, relative to the direction of the VOR.

DR. BERBAUM: Do you also have to include its density, the number of long contours?

DR. EBENHOLTZ: Yes. If you know enough, you should. Yes.

DR. KENNEDY: And if it's a scene, you have different things moving as a function of their distances, they are moving at different rates.

DR. EBENHOLTZ: But, you know, you can get an idea sometimes you can develop approximations to these things where it may be overwhelming to do it perfectly. You can sometimes develop an approximation approach. And the one thing I would want to know is where those eyes are relative to certain key objects in the scene. I mean, what is the pilot looking at to give it time? Where was the eye? How many corrective saccades did he have to make in order to keep his eye on that target? I mean, that by itself would be a poor measure of error.

DR. MCCAULEY: So you need to be measuring helmet position and eye tracking, and key targets or whatever we're showing out in the visual display; is that right?

DR. EBENHOLTZ: That's right.

DR. MAY: Well, if it's a complex scene how do you know the subject is tracking with a fovea, for example. If he doesn't need detailed information, he can be tracking the path of the object parafoveally, and then only if he wants to see some detail does he fixate. That's really a complex problem.

DR. EBENHOLTZ: It's a very complex problem. But you have got to know what kind of volume of errors are occurring in a particular unit of time.

DR. MAY: Without knowing what part of his retina he is using, how do you know whether you are computing errors?

DR. EBENHOLTZ: You have to know what he is looking at.

DR. MAY: And what part of the retina he is using to look at it with.

DR. EBENHOLTZ: His eye may be driven by peripheral stimulation. But he is probably looking with his fovea. Unless it's a very high, you know, very low frequency pattern he is not going to see anything. He is not going to see high frequency detail unless it's in the fovea.

DR. MAY: He can be three degrees away from the fovea.

DR. BERBAUM: You could actually instruct him to track a particular object, and then use saccades necessary to track it as a dependent measure of the degree of the conflict.

DR. EBENHOLTZ: There are a lot of things like that that could be done. For example, you can put on a pursuit target a target he has to track that would normally produce pursuit movement, and then you can calculate the number of saccades that intrude because of extraneous VOR that's pulling him off target. That by itself would go a long way to predicting some problems like eye strain and dizziness.

DR. MCCAULEY: Well, I think that in certain scenarios like air-to-air combat maneuvering simulators, they are usually at high altitudes so you don't have much rich detail of ground information like you do in helicopter simulators because the main thing he is looking for up there is the bogie, the bad guy. And you know that is what he is trying to look at. So wherever that thing is that's his target, it seems to me that that would simplify life a little. What you are trying to do here. So maybe it would be a matter of either doing this in those simulators that are dedicated to air combat maneuvering or configuring a research simulator for that task might be a good way to start.

15. Ebenholtz's Recommendations

15.1 Limit Vection

DR. EBENHOLTZ: There is another aspect to this that is just in terms of modulating these ill effects of exposure to the speed of the pattern. All right, we'll determine the demand that it makes on the eye. So you might want to modulate the velocities of these patterns or at least build up to perhaps what would be a truer representation, but build up to it in several stages. Don't just zap him, you know, with very high velocity patterns until he has had time to adapt his system to those.

DR. BERBAUM: In other words, when you start training him, keep him high so that he is not near the ground surface so that he is not getting a big vection factor, and slowly bring him in for more.

DR. EBEHNOLTZ: Yes, I wasn't thinking of that. That's one way to do it. I was thinking in terms of a digital system. A digital system during the whole thing, then you should be able to verify the velocity of that pattern just through a software parameter.

DR. BERBAUM: Well, you still have to simulate the real flight dynamics of an airplane moving through a scene, though.

DR. EBENHOLTZ: So you are forced to maintain certain velocities.

DR. MCCAULEY: With the pilot control.

DR. BERBAUM: But you could control that sort of thing indirectly by how close you let him get to patterns that could produce vection. We have talked a little bit about limiting the field of view for somebody who is having difficulty - starting them out with a narrower field of view, and then gradually building up to stronger stimuli for vection.

15.2 Strobe The Stimulus

DR. EBENHOLTZ: I only have three other points that I would like to raise. One is to consider what we know about the role of a strobing environment. We know, for example, that if you wear prisms in a strobing environment you will cut down the rate of adaptation, and also cut down the incidence of sickness. Now, to me what that means is that you're modulating the frequency of errors that these various oculo-systems have to process in a given unit of time. And it seems to me that it may be possible to work with that as an analogy and perhaps degrade a little bit the motion, the quality of the visual motion signal that you present to individuals.

DR. KENNEDY: Do you feel comfortable reviewing the Melville Jones work with different strobe frequencies and different on/off times?

DR. EBENHOLTZ: I haven't looked at that in a long time, but that's what it is based on. And there were no motion sickness symptoms?

DR. KENNEDY: At one frequency, but not another.

DR. DUNLAP: So, you have got a series of pictures as opposed to continual motion?

DR. EBENHOLTZ: It would be like a bad cartoon, staccato effect instead of good smooth, but that too could be seen in stages. It could start out with a lousy cartoon and work up to a good smooth movement.

MR. CHAMBERS: Here the engineers have been working hard to design simulators to give you the feeling of really flying and now we are saying get rid of that.

DR. EBENHOLTZ: Do it gradually.

DR. MCCAULEY: Maybe for only the first week.

MR. CHAMBERS: That's interesting.

15.3 Recalibration Of VOR

DR. EBENHOLTZ: A second point is to require very simple but normal VOR training after stepping out of the simulator, have them sit or stand at a target, a simple target, fixate the target, and move the head from side to side and up and down so that they get very specific practice at retraining a normal VOR, a VOR that requires the eye to move in a fully compensatory fashion immediately after leaving the training site.

DR. MCCAULEY: Could we have them play darts or as Fred Guedry suggested play ping-pong or something?

DR. EBENHOLTZ: Well, I think that's nice. It's nicer than staring at a dot moving your head back and forth, but I don't think it's as effective because it leaves it to chance that you are going to retain fixation for a long enough period of time to get enough retraining cycles in. In seven or eight minutes, I know that I can create a redirected VOR. So, I am talking about a compact period of time where you are putting in a lot of retraining that shouldn't be objectionable to anyone compared to the benefits for what you are going to get out of this. Very simple and direct exercise.

DR. MCCAULEY: Have you done this with the same people repeatedly over time? I am wondering if it takes eight minutes the first time or if it doesn't take six the next, etc.

DR. DUNLAP: So, what you are doing is recalibrating the VOR.

DR. EBENHOLTZ: Now, that might leave them with their learned adaptations, but it would at least insure that the distortions are not going to follow them.

15.4 Demodulate Vestibular Nucleus With A Circular Surround

DR. EBENHOLTZ: There is just a third point that I wanted to leave you with. The site of where I think all this mischief is occurring is the first site that we know of where vestibular interactions are occurring: the vestibular nucleus. That's a very interesting region because apparently there is a proprioceptive information registering there along with auditory information, visual information, vestibular information.

The idea is to modulate the vestibular nucleus to work for you instead of against you. The premise is that visual inputs we know they are modulating the same cells that normally get driven by a motor response, by an inertial stimulus. So, the idea then is to play in visual stimuli that will demodulate the cell. Now, this can be done in a number of different ways. I described the effects of placing a simple, then, circular pattern around an oscillating square frame that was known to produce vection along with a subset of vertigo type symptoms. When an individual looks at this oscillating frame oscillating around the line of sight, but in the presence of this circular pattern the incidents of motion sickness symptoms diminish. No vection occurred among approximately a dozen subjects where as vection did occur among about four of them when the circle was not present.

Now, I construe these studies in terms of the action of that circular pattern on cells in the vestibular nucleus that would otherwise respond in terms of a motion signal produced by the oscillating frame. But because of the presence of a circumscribing circle, what you have got in the system, what the circle is doing in the system is simply presenting a population of receptors that represents every conceivable orientation to the nervous system. In other words, if you imagine the projection of the circle -- of an image of a circle on the periphery of the eye -- what you have to understand is that it's being processed by receptive fields that are very small. So when these receptive fields work at the edge of the circle, they don't see a circle, they are seeing a line at a particular angle in space. And consequently as far as the total input is concerned, we have orientations of every conceivable type that are represented in that vestibular nucleus. The net effect of that is to null out the effects of the tilting frame so that tilting frame is no longer modulating the cells that would normally be modulated if the circle were not present.

MR. CHAMBERS: In observing the area-of-interest displays in simulators where you have a high resolution area, you have a background scene that is low resolution, then you take another projector and project high resolution (small area) and it might contain, if it's on the ground, the tank and some information around it (the road). It will be high resolution where the road will continue in the background and then be fuzzy. Most of these are just slaved to the target. And some implementations of that effort (high resolution areas as a square) and some project them as a circle. I find the circle a lot more pleasing because I automatically don't have any orientation and don't try to orient to it either. The square forces me to try to orient, you know, and you have got horizon and texture rolling with respect to this fixed square, and you are constantly trying to orient something. And I asked about the diamond or rectangle because maybe the circle tends to shut down our desire to try to obtain orientation is all I am suggesting. Therefore, a circle seems best, but I wonder whether we have fully evaluated all other options (diamond, square, etc.).

16. Ebenholtz's View Of Conflict Theory

DR. BERBAUM: Would you care to summarize your thoughts about the conflict theory?

DR. EBENHOLTZ: I interpret the conflict theory in ways that I could deal with it more objectively than in terms of sensory perceptual stages. I would like to push that as far as it would go. Because I think you have a case where you could show it to be wrong. So the way in which conflict is defined from my point of view is simply in terms of the kinds of error correcting signals that you require of an eyeball in a given situation. The longer you're in it, the larger the magnitude, the more likely the incidence of complaint.

DR. BERBAUM: And so far as you are concerned, until proven otherwise, that's going to be a short-term history which is going to determine the current set point?

DR. EBENHOLTZ: That sounds correct.

DR. DUNLAP: Let me ask it another way. Do you think that would also be noticeable for motion sickness when aboard a fishing boat, where you don't notice you are going up and down, but all of a sudden you start getting sick, and you think you would pick it up in the eyes?

DR. EBENHOLTZ: Yes. I tend to focus on what I consider to be the initiating or determining conditions, and I think perception is at the end of the chain, and not at the beginning of it. I know that; I know it runs counter to feelings of a lot of people.

DR. DUNLAP: I mean that's obviously testable, and maybe in the simplest case is the up-and-down motion that's almost below threshold or what we call threshold, which we don't really know what it is. Because obviously something senses that motion because you get sick.

DR. KENNEDY: There is also a conflict with linear oscillation, according to Alan Benson, if you ask people to tell you where the turn in direction is. For linear oscillation (in the frequency ranges where people are getting sick) you misperceive where you change direction.

DR. MCCAULEY: It's a phase advance. He says there is a phase advance.

DR. KENNEDY: Yes.

17. McCauley's Views

17.1 Dual Adaptation To Simulator And Aircraft

MR. WILKES: Mike, do you agree that it would be helpful to examine people that have been in a simulator a very short time before and after they get in the aircraft, and again before and after the simulator, and then the aircraft and so on? Examine transfer of adaptation from simulator to aircraft, back and forth.

DR. MCCAULEY: That's the conclusion that I have reached. You want to achieve a state of dual adaptation, contingent adaptation, where the individual is completely adapted to both the simulator and the aircraft. And at the beginning, it's differences in those two environments that may be the major cause of simulator sickness. It's like operating with your glasses off and your glasses on. You do them both often enough that you can operate either way.

17.2 The Real Problems In Simulator Sickness: Detrimental Influences On Pilot Selection And Negative Transfer Of Adaptation To Aircraft

DR. MCCAULEY: There are a couple of things I want to say just from the way I view this problem. There is no question in my mind that there is some substantial incidence of simulator sickness out there that people are starting to recognize it. The next question is, so what? How much of a problem is it? If a small percentage of aviators feel a little nauseous once in awhile maybe that's no big deal. But I would say that there probably are a couple of situations that you want to avoid. One is that training itself in a simulator is compromised because of the sickness, even possibly worse than that that you may wash out a certain percentage of students based on simulator sickness when in fact they may be excellent pilots. I would almost wonder if some of the people with more sensitive vestibular systems, who maybe are excellent pilots, aren't the ones who have a problem with simulator sickness. I don't know that. But that gets very expensive for the Navy to washout people who would in fact be good aviators, but are having a problem with simulators.

DR. KENNEDY: I don't know if anybody has washed out from simulator sickness at all. And the likelihood of having simulators interpreted as selection devices is small, but that might make worthwhile study.

MR. WILKES: Is it ever used for any criterion judgment making on an individual as opposed to just flat training at any time?

DR. KENNEDY: As you know, you can't separate the impression that an instructor has over a student relative to whether the fellow has the right stuff or not. And so certainly people who are going to get sick in simulators when instructed by senior officers, may have an influence on their assignments, training grades, etc.

DR. MCCAULEY: My impression is that the instructors look on this as a weakness. The guy doesn't have the right stuff; he is getting sick in the simulator even if he is not getting sick in the aircraft. Another thing I want to point out may be an answer to the "so what." The possibility of the negative transfer of perceptual adaptation in the simulator may be maladaptive in the aircraft. There are a lot of questions to be answered about the time, the delay of the effect, how long after a simulator exposure should a pilot be able to go flying in the aircraft. If he inadvertently gets to an IFR situation, is the probability increased that he is going to get some perceptual problems, the leans or something? I would be afraid that the adaptation to the simulation environment would be a good thing for reducing motion sickness in the simulator, but a bad thing for performance in the aircraft for some amount of time until you achieve the state that we started out talking about there, which is your dual adaptation.

17.3 Restrictions On Post-Simulator Flight

DR. KENNEDY: If I have no symptoms from a simulator that creates symptoms in 20 percent of the people, should I be restricted from flying an aircraft? Would you say in that day or whatever we set up as our safety factor? Nobody flies an aircraft for 24 hours, let's say or no one flies an aircraft within 12 hours of leaving a simulator. Would you say that is a fair thing to have for a person who has had no symptoms while he was in? We have some reason to believe that persons exhibiting sickness <u>and</u> postural disequilibrium changes may be more at risk than experiencing either alone.

DR. MCCAULEY: I think I would try to come up with a basic set of rules for use of the simulator in scheduling flight training for a particular training squadron. What you do in a helicopter simulator in one place shouldn't necessarily apply to air combat maneuvers simulator. I think one needs to come up with a set of rules that would be fairly conservative at the beginning. I would say the 12 hour rule is good; 12 hours after the very first exposure before they could fly the aircraft. And then you decrease that time.

DR. KENNEDY: Perhaps I am putting words in your mouth, but things that we think make a difference for post-adaptation effects are symptoms during adaptation. Is that a necessary relationship? It sounds like a reasonable thing to say if you have symptoms while you are in the simulator, you may have symptoms when you get out. Could be the other way! If you don't have symptoms while you are in means you are adapted, then you may have some post-adaptation effects afterwards.

DR. MCCAULEY: That's right. That's why I wouldn't accept that at the beginning. I would make a blanket rule for everybody. For those with the small percentage who are having severe symptoms, you need some type of remedial program. You need to work with them in whatever way seems best. Tom's [Dobie] sort of approach, salvage these guys before they start getting behind the power curve. I guess this is not a large percentage of the population. I think you need a blanket restriction for everybody whether or not they have any symptoms. The rule should change quickly, so that by about the third or fourth hop in the simulator, we are down to maybe a couple of hours.

17.4 Restrictions Should Depend On Kinematics

DR. KENNEDY: So in terms of restriction, probably no restriction for after say one-third of the way through the syllabus, but restriction at least based on what we see as the data, I guess, we have to go to the data.

DR. BERBAUM: Maybe it depends though on the mix of kinematics.

DR. KENNEDY: Yes, that's what I am saying. We have got to go to the data to find out what the symptoms are. But we ought to be able to come out of the data with some suggestions that this particular simulator typically happens shortly after the following hops. The restrictions ought to be keyed toward those hops if you want to put them earlier, and so on.

DR. MCCAULEY: That's another point I didn't bring up. Instead of just the hop number as in first, second, third, fourth, there are certain hops when according to the syllabus they are doing certain more dynamic things. So, it may be that they are bothered on a very first hop because it's new, and then that goes away. Then they don't have any problem until hop number six when they are starting to use the helicopter to go aboard ship. And you have a lot of dynamics out there. And that may be a problem hop. So you should again not allow them to fly the aircraft.

DR. KENNEDY: We plotted the 30 or so hops from LeMoore, and we plotted the incidence per each, recognizing that some people repeated themselves while some were brand new. We only had about 80 cases. But there are three distinct bumps. The first bump was small, and occurring shortly after introduction into the aircraft. The second bump was smaller, and occurring as aerobatics were introduced. The third much later and bigger bump occurred with gunnery.

DR. MCCAULEY: I was there when we were initially talking to flight instructors and people who were some of the first ones to go through the simulator. And they told us that in advance, repeatedly, "Well, I never had any problem until hop number eight. That was a problem because we were doing all kinds of whifferdills and that really got me."

DR. DOBIE: I noticed, as others have, that symptoms can come back again with a change of aircraft type. In our RAF, people who change their aircraft's roll, as with a bomber force predominantly doing a high-low-high configuration changing to a low level operational tactic, then they enter into a new world, and motion sickness comes back again.

18. Incidence Of Sickness In Newer Simulators

DR. DOBIE: Is the situation getting worse or better with changes in simulators?

DR. MCCAULEY: I think the incidence is going up.

MR. CHAMBERS: Incidence, severe incidence, is going up, predominantly on simulators with wide-angle vision. And there are still a lot of instrument simulators out there.

19. The Incidence Of Aircraft Fatality

DR. BERBAUM: With the new wide angle systems you may get more sickness. But, I think you also have to look at the data on accidents. Are the rate of real aircraft accidents going up or down as the new simulators are being used? I think accident rates are going down. So, you may not want to base your decision about whether to get rid of these fancy new devices, just on sickness.

DR. MCCAULEY: Of course not, no.

DR. EBENHOLTZ: Grant McNaughton and others claim, conservatively, that about 15 percent of aircraft fatalities are due to disorientation. This is a piece of evidence that is quite contrary to the reports of pilots. So that I could only conclude that there is a lot of reticence to describe such experiences.

DR. KENNEDY: That is not true. Pilots report vertigo and they do so aptly. I believe they are quite willing to describe their disorientation experiences.

DR. EBENHOLTZ: You weren't counting disorientation as part of motion sickness?

DR. KENNEDY: No.

DR. EBENHOLTZ: Why not?

DR. KENNEDY: I don't think it is the same kind of thing. It's related, of course, but people get sick without disorientation and the converse.

DR. EBENHOLTZ: Isn't that a subset at least of the symptoms we are talking about in simulators?

DR. KENNEDY: I think vertigo is, sure.

DR. EBENHOLTZ: It may be that we might be judging the simulators too harshly, and that at least some part of the symptoms produced in simulators is in fact reflexive.

DR. KENNEDY: I think that there are conditions within aircraft which can result in vertigo. The conditions which promote it are very difficult to pull together. However, the incidence in aircraft of vertigo is much lower than the incidence of vertigo in simulators in general.

20. Data Collection During Retrofits: Testing The Success Of Recommendations

DR. DUNLAP: I think we ought to recommend online data collection. If we are going to introduce a fix, I think we have to have a way of measuring what happened before the fix and what happened after it. Otherwise, we are just turning knobs in the dark.

DR. KENNEDY: I think there are specific experiments that may have high payoff for economic reasons and have a high likelihood of success. I think that there is a family of criteria we could apply in order to recommend such things. But, I think that some of our recommendations ought to be keyed toward existing online simulators that can be modified or guidelines for people in order to modify how they approach the simulator.

DR. MAY: I think you are right. I think especially putting some way to get data out of the simulator before and after any fix is put in is critical.

DR. KENNEDY: I don't have any problem with that. I think what we ought to propose is a series of fixes, a series of recommendations, and then when we come up against a roadblock because of inadequate information, then I think it is inescapable that there are things that need to be done and fairly soon in order to move along.

What I would hope to avoid is having this assembly go down some research pathway in order to try to compose an entire research program.

CHAPTER VII

Discussion with Laurence Young, Ph.D., and Donald Parker, Ph.D.
September 27, 1985 - Morning Session

1. The Possibility Of Vestibular Masking

DR. BERBAUM: In this morning's session we'd like to focus on the ideas of Dr. Parker and Dr. Young. Would you like to describe your research or begin with the discussion questions you feel particularly interested in addressing.

DR. PARKER: There are two or three things that I'd like to comment on. Let me just make some comments on questions 9 and 25, which seem to me very similar, because that's something people were talking about last night. Then I think I could respond to questions you might have.

Questions 9 and 25 seem to me to address, at least in part, the issue of a vestibular mask. There is a huge literature on masking in vision and auditory areas, but most of these deal with masking within modality. Evaluation of cross-modalities masking, in so far as I am aware, is not very well developed.

DR. EBENHOLTZ: No, the point of putting in vestibular masking would be to mask out whatever signals are there to defeat the lack or correspondence between visual and vestibular by taking vestibular out of the equation by masking within modality.

1.1 Parker's Proposed Capture Experiment

DR. PARKER: If we view the modality by considering it's a spatial orientation system, then both vision and vestibular-tactile contribute. If you want to evaluate the possibility of using vestibular masking without going to the expense of having a complex jiggling system, unless that's readily obtainable within the simulators already, it seems to me you might try the procedures of Warren and Welsh on visual capture.

I don't know if you recall, but there's an article, I think in Psychological Bulletin or Psychological Review within the past six or eight years that talks about the relative amount of capture of an auditory stimulus. Using that paradigm it seems like you could jiggle the auditory system spatially. It's a spatial paradigm. You could spatially jiggle either the auditory or visual stimulus and check the degree of capture by the non-jiggle, non-noise modality. The point is this is a relatively cheap way to approach that problem without going into the expense of reprogramming simulators or designing simulators that would give you relatively higher frequencies, I think.

DR. DUNLAP: Though I would interject that Walt has told us that some of these things are already set up to do shudders and shakes as part of the simulation itself. So we may be able to find a simulator that already has the mechanism to actually do it with the motion base.

DR. PARKER: Well, that is an alternative way of going about it, and it may be most wise to go directly to the shaking device.

1.2 Young's Experiment - Vestibular Masking Impossible

DR. YOUNG: We had tried about ten years ago to see how much you could increase the threshold of perception by superimposing vibrations. And we did the experiments preliminarily at MIT. John Stewart and Brad Clark did it on the MCRD man-carrying rotation device first. It bears on the question of vestibular masking, superimposing noise.

What we first did was measured vestibular threshold, the time to get to angular acceleration and then superimposed a sinusoidal oscillation.

DR. MCCAULEY: In what axis?

DR. YOUNG: Yaw axis. Yaw only had no effect, to our amazement did not raise the threshold. Tried a different frequency and it didn't seem to make any difference. Then we said, well, that's because the vibration we're putting in is sinusoidal and predictable. So we went and mixed it and put in a random-appearing one. And as I recall, that also had surprisingly little effect on the thresholds. As to my knowledge, the experiment has never been repeated by anybody else. And I'm not certain whether or not it was published. John Stewart was the principal author on it.

DR. PARKER: What was the frequency range of the noise?

DR. YOUNG: It was ball park of 1 Hertz. It was basically limited by the controlling characteristics on the MCRD. So that's the only experiment I know of which directly bears on the question of the efficacy of vestibular masking.

DR. DUNLAP: There's one advantage, though, in this situation, and that is that using a masking paradigm, but there's nothing to be masked, presumably there's no vestibular input when there should be in the simulator.

DR. PARKER: You're talking about on a fixed base?

DR. DUNLAP: Yes.

DR. YOUNG: I thought we were also referring to making up for inadequate vestibular cues.

DR. PARKER: And motion.

DR. YOUNG: Limited-motion simulator.

DR. DUNLAP: But if you think about a fixed base, the scene's moving, you're feeling vection, and, of course, there's no input from the vestibular, and maybe these joggles and shakes would tend to say, "Well, I couldn't get any information out of that vestibular system, anyway, that's useful," because of the randomness of it. The idea would be to turn down the gain.

DR. YOUNG: That was what was behind this, the theory of these experiments. The Kalman Filter model of sensory processing orientation that we have been playing with predicts when the noise on one channel increases, that you turn down the gain. And we were hoping to find that in this experiment, and it didn't really work out very well.

In another separate subject, another comment I had on hardware is that it's quite common to have a buffet, separate buffet controller on a simulator. What that usually does is shake only the seat and not the cab. But that would be certainly adequate to try out this. I don't think you would have to have a full-motion system to do it. And those usually go to high frequencies.

DR. DUNLAP: So we could probably put this pretty far down the list as a pretty speculative thing that still maybe should be looked at.

DR. YOUNG: Speculative but very easy to try.

2. Measuring Inertial Motion

2.1 Effects Of Low Frequency Vibration

DR. PARKER: There's some concern when you get into fairly high amplitudes of a low frequency vibration. We had some evidence that we believed could be interpreted as a temporary threshold shift in the vestibular system. And you're always worried about the potential of some environment creating situations where people fall or become disoriented. You don't want people damaging themselves coming out of there. ISO Standards, used to perform vibration inspections, are supposed to extend down into the low-frequency range. But as far as I know, the ISO deals with tissue damage, rather than performance decrement.

DR. MCCAULEY: There's three curves: Fatigue, decreased proficiency, performance and safety. Safety is way up there. In other words, you are going to get hurt if you exceed this.

DR. PARKER: I don't know how good that data is for very low-frequency range.

DR. MCCAULEY: Well, Kennedy and I wrote a paper that goes down to 1 Hertz. And we extended that below 1 Hertz, but we had to use different criterion rather than one of those three I described. We used motion sickness. That's been adopted as a military standard.

2.2 Measuring Low Frequency Vibration

DR. KENNEDY: There were two people who went out to one simulator on two occasions, deliberately to measure the stimulus and have come back and said that there's not much below 1 Hertz. When the question was put to them, "How much energy is there below 1 Hertz?", "There's not very much." But that's not good enough, really. "Not very much" to a person who's interested in structural cracks at 50 Hertz is just not the right question.

DR. PARKER: Or fatigue or performance.

DR. KENNEDY: The second thing is, with structural crack equipment, you don't measure blow 1 Hertz particularly well. Does it not require special attention to pick up all the energy below 1 Hertz?

DR. YOUNG: If you're using accelerometers, it requires the same class of accelerometers to go below lower frequencies, but it is more tricky, pushing the state-of-the-art.

DR. PARKER: My belief is that most guys who go out measuring vibrations conceive a vibration as everything over 1 Hertz and their accelerometers that they carry around in their little satchels will measure that.

DR. YOUNG: The person I know who was the principal expert on this is Tabak who used to be at Langley, now at Bionetics, in Hampton, Virginia. He went around and he did a survey of all the NASA linear acceleration portable packets.

DR. KENNEDY: In your estimation, if someone were interested in measuring the energy in X, Y, Z axes and planes in simulators, could it be accomplished by one person going to all the various places? What would that cost, for measuring the force environment for maybe four or five different scenarios, four or five pilots with different characteristics?

2.2.1 The Importance Of Measuring With Particular Pilots

DR. YOUNG: You are interested in measuring the characteristics in a pilot and simulator, not just of the simulator itself?

DR. KENNEDY: If you answer the question with the number, then I will tell you the why.

DR. YOUNG: My question is are you just interested in characterizing a simulator?

DR. KENNEDY: Yes.

DR. YOUNG: Not the effect of having a pilot in the simulator?

DR. KENNEDY: That, too. At Tustin there area few simulators that are side by side, and you can stand in the anteroom and view them both from outside. They are both helicopter simulators and they have similar data bases. They have slightly different characteristics and slightly different missions. If you stand outside you can see and compare the two. On one occasion, I observed that the one on the left was all over the sky. The instructor explained that the fellow on the left was a new guy; that he'd got his wings but had only got 80, 90 hours in helicopters. The fellow on the right was a second-tour guy, so his ability to handle the plant dynamics is better.

If there is energy at two tenths of a Hertz, I would guess the new fellow is generating and exposed to far more than the other regardless of the task. And if we believe all of McCauley's data on whole-body sinusoidal oscillation, this new fellow might be getting more sick just because of move energy at two-tenths. There are reasons why the experienced person gets sick, which are due to his past history or neural store. If a person were to go out there and measure the simulator, they would have to measure it with someone in it. It might be useful to know whether there is a lot of energy around two-tenths. The SAAC simulator that our instructors evaluated, the meter stick suggests that two-tenths is about where it was.

DR. MCCAULEY: That's a long question.

2.2.2 Two Measurement Packages

DR. YOUNG: The answer is yes. There are two approaches to making the measurement. It basically has to do with sensitivity. One is to have a standard package that is brought around to each simulator, nail it on.

Those exist. They are either high quality, or take them off the missile guidance system. They exist in low quality. There was also a low quality one that was used by NASA Langley in a contract with Piedmont Airlines. They measured the aircraft acceleration and compared that with motion sickness symptoms of the passengers. Those things are available. If you took the route of using an existing package, we could say how much would it cost, or how much time would it take to do the evaluation.

The other route is to take the existing information that's in the computer of each simulator. It has buried in it a number which shows you at every step what's the length of each post. You can derive the accelerations from each simulator. That requires less hardware but probably more work because of the software. If you buy or borrow an existing package with an instrumentation recorder and go around, strapping it on the simulator and taking the measurements, then I think that for each simulator you are talking about two weeks of data taking and two weeks of data reduction.

One other point. If you're concerned about higher frequency motions, frequencies above 2 Hertz, then you need some kind of strap-on package.

DR. KENNEDY: I don't know whether we should, but my hunch is that that's not where the simsick problems are.

DR. PARKER: You turn down or make the vestibular signal less useful, as a consequence of that you hope to increase the gain of the visual input. But you also get greater reliance on proprioceptive tactile sensories, which are still inappropriate for the visual scene translations and rotations. You're now getting proprioceptive input in the range of 60 Hertz.

DR. MCCAULEY: If you have certain resonances in certain simulators, you may get visual effects. Your eyeball starts to bounce around at something like 40 or 50 Hertz. So that could affect one's perception of visual display and thereby interact with the vestibular. That's a long shot, but I think you need to watch out for that.

3. Measuring Simulator Visual Systems

DR. BERBAUM: I want to follow up on measuring visual systems. We talked about sensory conflict producing sickness, which of those conflicts occur in the simulator and not in the aircraft and so forth. But until we get a good characterization of what the signal is in terms of the inertial environment and in terms of visual, it's going to be very hard to really know what we're talking about.

It's particularly hard when it comes to the visual environment, because while it's fairly straightforward to get a measure of latency, it's very hard to get an idea of the psychological amplitude of the signal because salience depends on what surfaces are close to the individual, defining the space.

3.1 AGARD Work Group Ten On Assessment Of Simulator Engineering Characteristics Versus Salience

DR. YOUNG: I mentioned last night that there is a body of information available, and I believe it was in the AGARD work group ten on assessment of simulator engineering characteristics, not to be confused with the one on simulator fidelity requirements. I believe they go into specific suggestions of how to assess the engineering characteristics of a visual system and of a motion simulator.

DR. MCCAULEY: The question that seems important to me is how to get to the perceived motion. Information of engineering characteristics of the display is a starting point. But you need to know what it means to the individual who is seeing it, relative to perceived self-motion.

3.2 Is Visual/Vestibular Conflict Detected By Retinal Slip

DR. PARKER: Let's start with a hypothesis and try and sort it out. Make that hypothesis that in this situation we're dealing with, the primary conflict is visual/vestibular, and the way that conflict is detected is by retinal slip. So an assessment of integrated magnitude and time of retinal slip gives you a metric of conflict.

DR. MCCAULEY: That's what Ebenholtz said yesterday.

DR. PARKER: I didn't have the sense that that was something that you resonated to immediately.

3.2.1 Sickness Without Retinal Slip

DR. YOUNG: No, I don't, unless convinced. Simply because you can develop the conflict and symptoms of sickness without retinal slip.

DR. PARKER: In a visual/vestibular conflict, not in vestibular/vestibular.

DR. YOUNG: In the usual case, there is a head-fixed fixation, visual suppression of the vestibular nystagmus in which you have very little retinal slip, but enormous effort to maintain the fixation point, use of the pursuit system to overcome what would otherwise be a slip of the image.

The clearest example of that is the Mike Lentz/Fred Guedry test in which the subject goes through sinusoidal oscillation about the yaw axis and tries to read a table of numbers which are fixed. The numbers are of such a size that you really have to have fairly good fixation to do it. And there is a case where the vestibular drive is trying to go and space stabilize your eyes. Visual has to overcome to head stabilize your eyes. Very little retinal slip, there is probably some micronystagmus. Yet subjects develop symptoms of motion sickness fairly rapidly.

DR. PARKER: On the other hand, how about the reports about the stroboscopic presentation with the image reversing prism? As I understood, that the most sickness was much attenuated as was adaptation. When you have the stroboscopic environment which suggests that you have a retinal slip signal, both to get the adaptation and the conflict.

DR. YOUNG: I believe that. That's Melvill Jones.

3.3 Measuring Retinal Slip

DR. DUNLAP: How do you measure retinal slip?

DR. YOUNG: Practically?

DR. DUNLAP: Yes, the easiest, simplest way.

DR. YOUNG: I measure eye position, eye position in space and target position in space, and subtract the two eye positions. Eye and head plus head in cockpit.

DR. PARKER: But a saccade is not a retinal slip.

DR. YOUNG: During nonsaccade.

DR. MCCAULEY: So it's a distance It's not a slip as in velocity measure; is it

DR. WELSH: It's a mismatch.

DR. YOUNG: We usually think about it as velocity.

DR. EBENHOLTZ: But you could get something proportional to it if, for example, you measured a number of saccades in what would otherwise be a smooth pursuit movement, because it's an indicator that the system has to make some sort of correction. You may not want to label it as a retinal slip, but it's an indicator of work in the system. And I think that's part of what you want to get at.

DR. YOUNG: That's true. But it's a very rough approximation, because you have the same retinal slip or the same insufficiency of pursuit corrected by many small saccades or one large one.

DR. PARKER: There are individual differences in that characteristic.

DR. DUNLAP: So a root means square error over time, the actual position relative to the pupil or the eye position?

DR. YOUNG: You really have to deal with velocity and not position, I think, because the retinal position errors are, first of all, directed by saccades which nobody seems to think are involved in this problem. To use position as an input you have to presume that you know what the pilot should be looking at, and you know which target he's interested in at the moment. And we normally don't unless you're dealing with a simple lab experiment with one dot that's homogeneous.

DR. MCCAULEY: How about air combat maneuvers? That's probably the only thing he's interested in.

DR. YOUNG: I'm not sure.

DR. PARKER: He may have a display or may be looking around.

DR. YOUNG: And furthermore he may be scanning that aircraft, if you want to go and try to guess what the direction of acceleration vector is of that aircraft, he is probably looking around.

3.4 Parker's Retinal Slip Experiment

DR. PARKER: In contrast to what you people are trying to do, I'm trying to produce motion sickness in simulators. One of the experiments that I'm pursuing currently deals directly with the retinal slip phenomenon, where we're assessing the efficacy of training by recording eye movements during roll in darkness before and after exposure to a tilt of the body and a translation of the scene.

We've been getting some fairly strange results and we feel in part that must be due to instructions to the subject and how he's doing while in the training environment. So the study we're undertaking now is to have a subject track a target that's moving in translation while they tilt, or focus on a target that moves in tilt with them while the scene slips relative to that target. So we're trying to get at ways of producing adaptation faster and perhaps motion sickness faster. So that's at least one thing I'm trying to do in an experiment we're currently undertaking.

4. Sensory Conflict Theory

DR. KENNEDY: Do you believe that motion sickness can be due to one cause? It may be possible, within a given set of circumstances, where I would have a conflict and you would not, depending on our individual exposure histories. In one case conflicts may be due to energy at two-tenths Hertz, and in another case they may be due to a certain past experience that hasn't got anything to do with two-tenths.

4.1 The Evolutionary Theory Of Labyrinthine Involvement - Dr. Parker

DR. PARKER: Let me respond: I buy the evolutionary theory of the labyrinthine involvement in motion sickness. I find that more persuasive, given the studies that vertigo associated with renal failure and the observations suggesting that the ear filters very much like a kidney does, makes it into a very nice detector with appropriate sensory supplies for various kinds of poisons. Given that, it must follow that anything that will disturb the labyrinth will produce the symptoms of motion sickness. In space research we worry a lot about fluid shifts. There may be changes associated with fluid shifts or fluid imbalances that contribute to motion sickness.

There are situations that we understand, however, in the space case, where the conflicts are very clear. And it seems to me that if there's a body of ground-based testing literature, saying this is certainly the primary cause of motion sickness for most people in space. This fluid shift is at least tertiary. There are studies that suggest certain kinds of visual/vestibular or vestibular/vestibular conflicts will consistently produce motion sickness. So why go racing off for this miniscule, one-half percent cause, first off, in your data? I do buy the extended sensorimotor conflict theory, and it doesn't depend upon whether I agree with the evolutionary theory or not, because it doesn't say anything--unfortunately. The sensorimotor conflict theory has two major problems. One is it doesn't help us at all in understanding mechanism.

DR. YOUNG: Except it leads you to search for the magic conflict neuron which has not yet been found.

DR. PARKER: The second problem is that it's not really a theory. What it is is a construct, because any time a new situation arises that produces motion sickness, you have to then go and say, "Where do I think there might be a conflict?" And in its extended form, it says that you can produce a conflict intravestibular, vestibular/visual, presumably vestibular/tactile or vestibular/auditory, but also between any of the senses and the expected output as a result of the voluntary motion or their expected output as the result of neural-stored predictor.

Therefore, you can go and dream up your best guess as to what the subject's expectation of the motion will be and find that in conflict with what's shown in the visual or vestibular stimuli; and therefore bring that forth as the explanation. So that's why it's not really a theory. The weak part of it is that you can always make it work.

However, having said that, there is no form of development of motion sickness that I know of that you cannot bring into conformity with the sensorimotor conflict hypothesis. And to take the toughest one that I know of, what Graybiel used to call the otolith overload, just straight vertical oscillation at point two-tenths of a Hertz. Where's the conflict? Well, there you have to go and speculate. There's the biomechanical explanation, let's leave that aside. But to look at the sensory one, you might say that point two-tenths of a Hertz could be a frequency at which the saccular transduction of acceleration is particularly poor; and, therefore, that's the place where you start to get a breakdown between the ability of the brain to make a prediction about your vertical motion and the feedback you're getting from the otolith.

DR. MCCAULEY: Alan Benson struggled with that and suggested there's a phase advance. And then you take that a step further and you say, well, the phase advances the conflict.

DR. YOUNG: The one thing we do know is that in vertical oscillations there is ambiguity in up/down, which doesn't have a parallel to left/right ambiguity or lateral disorders. Whether that's particularly frequency sensitive or not I don't think has been established. But I bring that up kind of in a sense that that's the toughest case I know to try to bring in the sensory conflict theory. And even there one could dream up an argument.

4.2 Must The Conflict Be Perceived?

DR. EBENHOLTZ: I have a question: Where's the ambiguity at the perceptual level?

DR. YOUNG: You know that you're turned around but you are not quite sure when or even which way. Sometimes you confuse the top of the cycle with the bottom of the cycle. This is even worse--we have been doing a lot of horizontal Z axis acceleration.

DR. MCCAULEY: Do you get people sick doing that?

DR. YOUNG: Yes, considerably more than with the Y axis, although it's still a fairly low incidence. But the confusion is there.

Let me preface this by saying I'm not doing motion sickness experiments, but sometimes people get motion sick.

DR. DUNLAP: Would you think it possible to get motion sick with vibration, vertical oscillations that are below sensory threshold, at least at the conscious level?

DR. MCCAULEY: In our studies, at very low accelerations levels, it doesn't matter what the frequency is, you get almost no one sick.

DR. DUNLAP: If you could make a person sick without even the conscious awareness of moving, what's conflicting with what?

DR. YOUNG: I don't think that's a requirement, that the conflict be perceived.

DR. PARKER: Certainly the conflict occurs in very low levels in the central nervous system, presumably the vestibular nuclei.

DR. YOUNG: Let's take a simple example of the motion sick symptoms that appear with a small change in magnification when you change your eye glasses. It's a very common observation that people come back and they don't usually complain about the world seeming to swim; they complain that they are having headache and dizziness and nausea.

DR. PARKER: How do they deal with that? They take off their glasses and adapt progressively, step-wise, just like the recent study on asymptomatic adaptation to slow rotation.

5. Adaptation As A Cue

5.1 State Dependence

DR. BERBAUM: What do you think of the idea of adaptation as a solution to simulator sickness?

DR. PARKER: One think you might want to do is make the characteristics of the adaptation--the simulator, very different from the real situation to induce perhaps a state-dependent learning for the simulator.

5.2 Perceptual Learning In The Simulator

DR. PARKER: In a very simple simulator for training of pilots, you're primarily focusing on the cognitive target of holding, following the vector airway. There are minor things you have to look at. You have to look at your altitude and a whole set of instruments. And so there's some minor motor responses. It doesn't seem to me possible that you could take the approach that we are primarily here dealing with training of the procedures in a simulator.

DR. KENNEDY: Nearly all simulators teach motor program, procedures. They are very effective at doing that. But the implication is that we can teach people how things look. The example that has been used is that a lot of *pilots claiming it takes to* 500 trials until the site depicted looks right, and sees the ground from the bottom up. There are other examples of size constancies that are learned.

DR. BERBAUM: Helicopter hover and landing on ships require a visual cue. That's also true of formation flight.

DR. PARKER: Okay, nevertheless, if you have a different simulator environment than real environment, ways that you could cue the subject that these are different environments, even though you're performing the same task with each environment, may be beneficial.

5.3 Limit Early Exposure Duration And Kinematics; The Effectiveness Of Adaptation May Depend Upon Pilot Experience

DR. YOUNG: What do you think about adaptation as a strategy And then, in answering it, Don brought up the question, in use of simulators for teaching sensorimotor coordination and realism versus non-realism-state adaptation, first-time adaptation, there are two obvious ways that you can do adaptation. One is by limiting the exposure time. The first few times in the simulator, regardless of his experience in the airplane, you start out with only a short hop and then gradually lengthen it.

The other way you can do it is by, independent of the exposure time by varying the conflict, you can go and start out with fairly gentle maneuvers, low turbulence, and then gradually build up to the full panoply of the more difficulty ones. I think both of those are reasonable things to do and should be explored. I'm not certain that the first one will really work, and the reason is that because we're dealing with highly experienced pilots who are continuing to fly the planes. It seems to me each time the pilot comes into the simulator he is coming in with this wealth of internal model of what the visual and motion should be doing when he gives a certain command. It doesn't matter how much time he spends in the simulator, it's not going to work. In other words, there's some reason to worry about the limited exposure. I think there's every reason to think that adaptation by limiting the extent of conflict in the simulator for the first few times and gradually increasing the turbulence and increasing the difficulty, changing from simple night visuals up to full-fledged day visuals and so on could help.

To Don's point about the state-dependent learning, I have two points. One is the use of drugs for state-dependent learning. We know that that can work, at least in rats running mazes. I think that's likely to be so impractical that it's probably not worth pursuing. The goal of this group is to find practical solutions. I think that is a neat research idea, but probably not a good practical one.

5.4 Maneuvers That Require High Fidelity

DR. YOUNG: And second, on the question of do we use simulators for teaching sensorimotor coordination, yes, I'd say more and more, both the undergraduate pilot training part of it. And the examples that come to mind are terrain avoidance, some of the more dangerous advanced procedures, like engine out on take-off, stall spin, some of the military combat maneuvers. It is something you have to get the pilot used to, because it's the only way he's going to survive in wartime. And you don't want to release pilots that are unable to release their straps in the aircraft.

Pop-up maneuvers. We could probably all think of other cases. Rapid identification of the nature of the target on the ground--is that a truck or a tank--while flying over it at high speeds. I think these are all cases in which you have to build up the sensorimotor, and which it is important to get as high a fidelity as you can get in the simulator, and not back off to the straight-back chair, sitting in an office practicing procedures at the console. I think my feeling is that we should not try to attack the simulator sickness problem by reducing the fidelity of simulators. There are some classes of its use that are not going to go away.

5.4.1 The Need For Better Motion Bases Rather Than Vestibular Masking

DR. PARKER: That's getting us right back to the first thing we addressed, which is vestibular masking, to the VOR, posturing reflexes, other extents of the vestibular system, the rest of the spatial orientation system and motor response system. Masking it isn't going to help that problem. It's suggested you need much better motion basis.

5.5 Contingent Adaptation

DR. BERBAUM: Can I ask a follow-up question here about adaptation? One strategy for using adaptation as a solution would depend partly on what one thinks about how adaptation works in terms of how the set points are controlled. Is that just based on recent history--just a recalibration, or are there contingent types of adaptation based on recognition? If recognition played a role, and you might train a person to feel comfortable with the spatial and temporal distortions in the simulator, those adaptations that may be unappropriate for aircraft will be engaged during actual flight.

DR. YOUNG: Kevin, we know that there are adaptations that depend on recognition of the state. And the most dramatic one I can think of is divers. A diver changes his VOR when an experienced diver puts on his mask. His VOR then changes as soon as his head hits the water. I forget what the magnitude of that is, but, you know, the gain I'm talking about is the very large. Gauthier showed that that takes place as soon as the mask goes on. That is a distortion which is every bit as large as the kind we're talking about. At any rate, there is evidence that you can adapt by recognizing a situation. You can adapt using the program that is appropriate for that sense. I think that may well take place in the simulator. The question is whether that decreases the value of the vestibular in teaching the flying task.

DR. BERBAUM: Can you make any recommendations for defeating the negative aspects of the adaptation?

DR. YOUNG: You had a number of specific questions in your list that dealt with that. You had several suggestions in there that seemed to me to be worthwhile following up. The question of richness of the visual scene and the potential for blurring, I think is an interesting thing and worth trying.

6. The Assumptions Of Sensory Conflict Theory

DR. KENNEDY: Let's go back to the conflict. Once or twice I've started off with the question, "Do we assume that more sickness occurs when there is more conflict?" People nod, then they think, "We don't really know." Is that a correct assumption? RPM makes a difference, more is worse. Velocity makes a difference, more is worse. Acceleration makes a difference, more is worse.

DR. YOUNG: The case that's particularly relevant to the flying situation is the Coriolis stimulus that results from the head movement in a constant right turn, which is not disturbing when you make the head movement two or three seconds after the initiation of the turn. But it is disturbing when you make the head movement two or three seconds after the initiation of the turn. But it is disturbing when you make it 30 seconds into the turn. The difference being that you are getting a vestibular/vestibular conflict.

In the second case, but not a larger one--in fact, I think they traced out a whole series of types that show that tertiary conflict is greater. The reports of the seriousness of the illusions increase. So I think there is not a large body, but there is some data that says more is worse.

DR. KENNEDY: Let me push the logic. Would we agree that you can get to some critical point where beyond that more conflict is going to be ignored.

DR. YOUNG: Yes, absolutely. You get so much conflict that one or the other of the sensory inputs is just totally disregarded. I've done some experiments on that; not regarding motion sickness, but regarding perception and control.

DR. KENNEDY: Do we know a corollary to explain that and can we use that kind of thing?

DR. YOUNG: The conflict model for perception of movement basically calculates this conflict at every moment of time and integrates it. As a result of that conflict you're changing the weighting on either the vestibular or the visual input. If the conflict remains small, that may be nausea, but not enough to result in much adaptation. If the conflict remains large, you just turn off one of them.

The obvious one is that if the visual scene is totally at odds with the vestibular input or the passive non-pilot, and it remains that way for some period of time, you turn off the visual input.

DR. DUNLAP: I think Crampton mentioned another way that it might work, and that is that when it gets so great you may just go into an illusion and sit back and watch it like a movie.

DR. YOUNG: I think that's consistent with what we're talking about. Very simply, if you're trying to develop vection, visually induce motion to a rotating field, and you suddenly move the chair in the direction opposite to that which is consistent with vection, the vection stops, and suddenly you are sitting there watching some stripes go by. We develop a conflict so large that one or the other of the inputs must be disregarded because you can't do a weighted average. Then in fact you end of turning one off.

6.1 Head Shaking

DR. DUNLAP: It's been claimed that when a pilot gets really disoriented he will just shake his head.

DR. YOUNG: Yes.

DR. DUNLAP: Which I sort of took as saying to the vestibular system, "Shut up."

DR. PARKER: Or, "Give me a signal that I know how to interpret." I shake my head and I know what to expect.

DR. DUNLAP: A reference of some sort.

DR. YOUNG: That is an anecdotal report that I've also heard. The explanation for it is not clear. Another possible solution is if you are in a constant turn, which is one of the chief ways of getting a conflict illusion, the visual scene seems to be turning and the vestibular systems tells you

you're not. If you shake your head in an out-of-play movement, you will then remodulate. Say you're in a constant yaw rate and you will build up a modulation of a condition which goes and reminds you that, yes, indeed, you're in a turn. So it's kind of a way to actually physically overcome the longtime constants of the vestibular system for a while. I guess your question, Bob, was can we say that more conflict is worse. And I would maintain yes.

DR. MCCAULEY: Yes, but up to a limit?

DR. YOUNG: Up to a limit, and then it becomes so much, so bad, that you might as well turn off the visual system because it's not being interpreted for spatial interpretation orientation.

7. Experimental Measures Of Sensory Conflict In The Simulator

DR. KENNEDY: Do we know some ways to frame that question and frame those limits?

DR. PARKER: Again, perhaps the Warren/Welsh paradigm might avail you with a way of approaching that question and what conditions do you use, auditory or visual capture, or between.

7.1 Dual Input Approach, Eye Movement Control Approach

DR. YOUNG: We've been approaching that: we have a paradigm using dual input, describing functions in which you independently derive visual, and then you allow the pilot to do a closed-loop control task, using whatever cues he wants, and by teasing out the frequency response, which frequency is the visual stimuli. And so you tease out the individual frequency responses to the visual and the inertial inputs, you can start to see at what frequency the pilot is on visual and vestibular.

The other approach which requires one more assumption is looking at eye movements. If you have platform motion and visual motion in which the optic motion is nystagmus, the eye movements are not the same as the vestibular ocular reflex, then you can start to look and see, well, are there situations in which vestibular starts to take over and the eyes are being driven according to VOR, rather than would be appropriate for visual field stabilization. That probably would be a situation in which you had started just to turn off the visual for perception.

7.2 Measure Acceleration Characteristics Of The Head

DR. KENNEDY: Shelly, you mentioned some of that this morning.

DR. EBENHOLTZ: By way of measuring whether the vestibular system is striving or whether you are in pursuit mode?

DR. KENNEDY: Yes, or are there some things that we could do that would be diagnostic with respect to learning the parameters of a particular person or in a particular scenario within a simulator?

DR. EBENHOLTZ: Well, for starts, try to get a description of the acceleration characteristics of the head by using these devices that can be strapped on. It still may be very difficult to characterize the simultaneous distribution of the optokinetic pattern which would be the ideal case. You would have to know the flow pattern and the acceleration operating on the head. Then you can infer the VOR from that, and what the exact distribution would be. I think it would be lovely to know just the distribution of force, the distribution of energy associated with the different planes of movement of the head.

Let's at least know the demand put on the VOR when you are in that simulator for a particular period of time, just for starts, because that's not known, I gather. So we don't even know what demands we are asking of the VOR.

7.3 Measure The Visual Simulation With Stripes

DR. KENNEDY: Should we go with the stripes in the simulator?

DR. EBENHOLTZ: No, people don't get sick with stripes. The problems you're interested in is not getting sick with the stripes.

DR. KENNEDY: We would understand better what was going on if we had stripes.

DR. YOUNG: My guess is, Bob, that that would make a nice publishable little experiment, but not advance toward your research very much. We did at one time compare stripes with realistic earth/sky background on the Langley dual maneuver experiment, which is a large simulator with a large point-life sort display, and a sphere that moves around. We were not measuring eye movement, merely measuring vection. We found no difference between stripes and realistic earth/sky scenes, whether standing on the platform or sitting in the cockpit.

DR. PARKER: What is the vection stimulus produced? What is the vection response produced? I would imagine the parameters that produce the greatest vection would also produce the greater nausea.

7.4 Target Acquisition Paradigm

DR. PARKER: Would you think a study using the kind of thing that Graham Barnes was doing, active head motion and the acquisition of the target, where you're perturbing either the scene where you have a scene motion or active head motion, then you also could crank in a vestibular stimulus. There you could begin to get at the relative control of the eye movement through vestibular and visual scene. That would be a nice academic study, would be a useful study for people trying to solve practical problems in simulators.

DR. KENNEDY: I'm trying to figure out if what's up there visually, with or without a motion-base, may not be producing a nauseogenic stimulus just by itself.

DR. EBENHOLTZ: I can give you a hunch on that. I would put an optokinetic pattern to maintain fixation so that could have produced an optokinetic stimulus that would command the eye in a totally different trajectory.

DR. KENNEDY: Would that be oscillatory or a constant velocity?

7.5 Visual Cues That Produce Sickness May Be The Ones That Produce Effective Simulation

7.5.1 Multi-axis Simulation

DR. YOUNG: My guess is that if you do it in a single axis, you are not going to find but a very small incidence of motion sickness, no matter how you place it, and you might go away disappointed from that study. I am basing this on a lo of people's single axis and linear work. I think sickness begins mostly after you start getting into multiple axis.

DR. EBENHOLTZ: Where the target and the background are in different directions?

DR. YOUNG: No, I mean where you may, for example, set up an initial yaw rate and then roll it.

7.5.2 Vection

DR. YOUNG: You asked before a question about the range of things one could look at in a visual system alone to find out what about the visual system is responsible for simulator sickness. This is not the same as saying, "What would you do to the visual system to fix it," because you may very well find that the very things that are primarily responsible for creating the simulator sickness are also the ones that make it an effective simulator tool.

The extreme example is if you turn off the visual system, the problem goes away. But so does the simulation. But the obvious ones are ones that were in your list of suggested topics. Field of view, I believe that the wider the field of view the more serious the simulator sickness problem is. I also believe the wider the field of view the better vection and the more effective the simulation.

DR. MCCAULEY: Would you use field of view in the first ten hops in the simulator or would you start with a narrow field of view and expand?

DR. YOUNG: That is one thing that I think is worth trying. All of these that you put in these suggestions are reasonable to try as an adaptation step. Starting with a narrow field of view is one.

7.5.3 Blurring The Periphery

DR. YOUNG: Brightness is another. Maybe start with night landings, which have fewer lights in them, fewer lines than full daylight. Then maybe start with dusk or fog and mist.

You talk about the benefit of defocusing because, at least I would assume that the very worst case is a case where you have a large number of very distinct, high-contrast visual elements that are moving in the periphery by going to night landings, going to fog and mist. Maybe that might elicit less of a conflict. This is all speculation and has to be tested.

DR. DUNLAP: Do you feel that if the scene were blurred it would induce less sickness?

DR. YOUNG: I think if the peripheral scene were blurred it might be. And it also might be less effective in developing vection, which is what you want to do.

DR. EBENHOLTZ: There is some data of Leibowitz' lab indicating that blurs are very ineffective stimulus in the periphery and there is some data in my own lab that indicates that blurs before you get a reduction, you have to blur so much that you're practically spreading the pattern over the entire field to make that very poor vection.

DR. YOUNG: I'm familiar with three other studies on it. Dichgans just told me about one he did. He did a study with blur and said that he got just as good vection as without it. Brandt claimed just the opposite. It's really important to have a firm, real, moving target when you talk about the pros and cons of using projectors versus using real moving screens. In our lab we've, without a single formal experiment, we've come to the conclusion that if we want good vection we have to move a true moving screen and not just a moving image. My conclusion is there is conflicting evidence on it.

DR. PARKER: But you'd know the peripheral had a very low spatial frequency response. Within that range a blur is not going to do anything for you until you get to the spatial frequency to which the peripheral system is sensitive, unless the subject makes active eye motions and looks occasionally at the peripheral scene.

DR. WELSH: Let me add something to this blur discussion. If you look at your hand through a prism you get visual capture, a blurred field gives you just as much visual capture as a clear view of the hand. An out-of-focus view of the hand through some kind of visual capture was undiminished, seeing your hand out of focus versus perfectly clearly, which goes against some notions. Also, it doesn't seem to make much difference if you see the tip of your finger versus your whole hand in terms of the size of it. So there is something very dominating about vision, even if it's not very good vision, in those situations.

7.5.4 The Importance Of Multi-axis Stimulation

DR. YOUNG: I want to be sure that you understood my point about the importance of doing any such proposed experiments for characteristics of visual scene. Those experiments, I think, should be multi-axis experiments and the simplest is yaw combined with pitch and roll.

DR. BERBAUM: Are you saying that you don't expect to get sickness without multi-axis stimulation.

DR. YOUNG: No. What I said was the experiments should be multi-axis because they are the most likely to give you simulator sickness results. There are certainly examples in which you'd get simulator sickness in a single axis, vertical oscillation being the most obvious.

7.6 Predicting Conflict

DR. BERBAUM: Can you predict what aspects of simulator motion are most likely to result in sickness?

DR. YOUNG: Somewhat, and I think my answer to that goes back to my answer to Bob's question about sensory conflict earlier. I think to the extent that we are able to calculate the sensory conflict involved in a certain simulator motion, either vestibular/vestibular or visual/vestibular, that which have a greater chance of producing simulator sickness.

DR. PARKER: We talked about frequencies where visual systems drive as opposed to frequencies where the vestibular system drives the VOR as breakpoint. A breakpoint frequency, is that the most likely to be one which is disturbing?

DR. YOUNG: My guess is that at the higher frequencies, the mismatch in the vestibular drive is going to create the main problem--higher frequency being above .5 Hertz--and that at the lower frequency the mismatch in the visual is going to be most disturbing.

8. Sensory Conflict Theory And Low-Level, Long-Term Stimulation

8.1 The Vestibular Nucleus

DR. DUNLAP: How about a pure vestibular theory of motion sickness?

DR. PARKER: Intravestibular otolith-canal?

DR. DUNLAP: How about simply a disagreement between the current vestibular input and what's expected based on the past

DR. YOUNG: That's really a subset of the sensorimotor conflict theory. I think that the notion that most of us carry around is that there is a movement detector which we happen to call the vestibular nucleus, but that's just an accident of how the name took place. And signals that are present in the nucleus represent an integration of information from all the sensory inputs about what you think your self-motion is. And conflicts occur distal to that, so that whether the conflict that occurs at the level that it appears--because of a signal at the vestibular nucleus--is the result of the canal and otolith stimulation. It doesn't matter if the vestibular nucleus tells you that it thinks you're turning to the left and suddenly you see a target that tells you that is consistent with turning to the right, you will get vertigo and disorientation.

DR. MCCAULEY: People don't get sick in the simulators without visual systems.

DR. DUNLAP: But blind people get sick aboard ship. You can't make LD subjects motion sick, and we've pushed that issue. Could you dream up a sensory mismatch of any other senses that they have that will make them sick?

The third point is that if you surgically destroy the vestibular apparatus, those subjects become sick when they come out of the anesthesia. That goes for five days. They can't prevent that either.

DR. YOUNG: Why do blind people still get sick? Well, there are intravestibular conflicts. Why do labyrinthine defectives not get sick? Because when you destroy the labyrinth, after a long recovery period, the function of the vestibular nuclei is gone, and that's an essential stage in the development of all kinds of motion sickness, regardless of whether there is vestibular input or not.

Reference Money's experiments on the emesis--dog vomiting with certain emetics and the fact that destruction of the vestibular apparatus will eliminate that vomiting. The third one is the fact that immediately following labyrinthine destruction subjects get motion sickness. Well, yes, because you now have a vastly different input to the vestibular nuclei, which are still functioning. So all of these cases are consistent with a sensory conflict theory which depends upon an intact signal of the vestibular nucleus which is related to some kind of integrated speedometer function.

8.2 Exposure Duration Versus Expectancy

DR. PARKER: But your question was a different issue, also. You asked about the situation where head motion occurs and the feedback is inappropriate. So you've got inappropriate signals, if you will. If you suggest that motion sickness is a consequence of the period of adaptation, the period of conflict, clearly there are cases of persistent conflict environments -- sailing, space flight -- where you get long-term exposure to an environment and persistent motion sickness. In those cases where you have a physically different signal present at the old visual system it's on, it does seem that three days or some fairly long time period is regarded for the adaptation.

On the other hand, I don't know of data that deals with the conflict between what I receive and what I expect to receive. But my guess would be in those cases adaptation would be relatively rapid and the provocative nature of the situation would be much reduced. And this goes back to the cognitive manipulations of VOR and very rapid changes that occur cognitively. And my assumption is that somehow resetting of the reafferent control system and reafferent feedback system might be a more cognitive process.

DR. EBENHOLTZ: Maybe we shouldn't bother with conflict. We should look at the characteristics of the vestibular nucleus and so on and see what's driving them. Just examine the vestibular system with regard to what kind of energy is needed to drive that vestibular nucleus, find boundaries within which no sickness emerges. That would represent the normal energy tolerance and then examine those cases where driving the nucleus results in sickness. And it doesn't matter how you drive it, you can get in with a number of different sensory stimuli.

DR. PARKER: The conflict theory does work in the sense that it allows you to predict whether a new environment will produce motion sickness. I've created a simulator, an environment, as far as I'm aware, nobody else has created. And with my new subjects most of them come out pale and sweating.

Each one of us could dream up a new environment that nobody else has ever created before and predict that 20 percent of the population would get motion sick.

DR. YOUNG: Furthermore, I guess in contradiction to Shelly's suggestion, those stimuli that you can dream up which do produce motion sickness, particularly one involving a visual scene, by analogue would produce modulation of the vestibular nucleus units far less than normal head movements produce, so that merely the strength of the modulation of units that the vestibular nucleus is not a good way of trying to tell whether or not stimuli that produced that modulation is going to be producing motion sickness.

DR. EBENHOLTZ: These are in monkey studies?

DR. YOUNG: We have no single units for men.

DR. EBENHOLTZ: It seems to me, though, that you do have evidence of even low-level stimulation producing sickness if you put a person just in a simple vection situation for the first time. There are awful lot of subjects who come out reporting a subset of motion sickness syndrome. So there is some kind of adaptation that has to be considered throughout consideration of all of those subjects, always sitting there, this problem of adaptation.

Consequently, before we can evaluate the range of stimulation that is needed, you have to have some sort of conditional statements about the experiences of the subject.

DR. YOUNG: I agree, and that's a good example where we know from extension of the monkey experiments what the magnitude of the modulation of signals of the vestibular nucleus and other parts of the brain is, compared to the modulation you get with the head movements. And the very same vection input you are giving the subject which may produce some motion sickness is one that gives you less of a modulation of the neural level than other natural head movements.

9. Nauseogenic Flight Maneuvers

9.1 Shuttle Flights: Pitch -- Roll -- Yaw

DR. KENNEDY: Don has some questions. For the record, why don't you go through the ones you feel you want to address.

DR. PARKER: I have one more question I wanted to briefly address. And that was question 5, on flight maneuvers that would be most nauseogenic. There is a set of observations from the shuttle flights suggesting that in terms of production of symptoms, pitch is more provocative than rolls which is much more provocative than yaw. The case for yaw is fairly interpretable. However, the difference between pitch and roll doesn't seem to be so readily interpretable because there's a similar conflict which suggests that in terms of producing a conflict that is salient for a subject, pitch has some unique characteristics. And those may be related to problems with falling, so one would predict just very generally from the observations in the space lab that pitch would be the most disturbing kind of stimulus.

9.2 Close Ground Interaction

DR. YOUNG: On what Don commented on earlier with respect to your question on what kind of maneuvers are likely to be the most provocative: I would also like to suggest that those maneuvers which put the pilot in close contact with the ground are likely to be the ones which are the most provocative for simulator sickness.

DR. KENNEDY: Kevin, do you want to make a statement about the ground plane imagery in Tustin? Was that not one of the complaints that you were making?

DR. BERBAUM: Yes. The difficulty is that as you approach the ground in many simulators the level of detail that you have in depiction reduces to nearly nothing. All the edges that are undergoing perspective change come together on the horizon, and you really just have a large sheet of color with no surface detail. So ground interactions become very difficult.

If you're an experienced pilot and you try to land in the simulator, it's not exactly clear how you're judging distance, but one cue involves movement of surface detail. And if you don't have that you're going to touch down early according to the motion base relative to the visual display. It's going to be anomalous. And then, if you get used to that lack of detail, it may happen that as you're coming down in the real helicopters and getting all this detail, you think you should be down when you're still far above the ground. You can't find it.

DR. DUNLAP: And pilots claim they land high in simulators.

DR. BERBAUM: There is one report where an individual practiced night landing in a simulator and then tried it in a real aircraft. As he came down he said, "Whoa, where's the ground?" He came back up and repeatedly was unable to find the ground and finally said, "Well, I'm just going to continue to descend because I know it's got to be down there somewhere." He finally got down.

DR. YOUNG: I'm basin my comments on primarily interviews with commercial pilots, their concerns about simulator sickness. And I find a combination of at least two factors; there's the visual scene close to the ground, which is a particularly bad problem. One is what you mentioned, lack of detail.

Secondly, the fact that objects are moving so quickly when you are in proximity to the ground, some of the break-up in the picture becomes more of a problem, the jagged edges. You have more distortion. Third is anxiety that is raised in the pilot as he comes closer to the ground so he isn't likely to be relaxed about it.

DR. BERBAUM: Another problem is the lack of scale information, even where there is good surface definition.

DR. YOUNG: That's something which I think is testable, because we have the newer-generation daylight scenes with the textures in the pattern.

DR. BERBAUM: Are you talking about computer generated synthetic imagery where photographic textures are put on the surfaces?

DR. YOUNG: Yes. Those are clearly much better at giving you some set of scale than are the homogeneous polygons. So you can switch a given CGI with texture in or out and see if that is a factor. I assume it will be.

9.3 Trading Transfer of Training For Reduced Sickness

DR. MCCAULEY: I wanted to throw one other think into the ball game here to make a complex issue more difficult. I think that we never need to lose sight of the fact that we may have to trade off simulator sickness against transfer training. Any of these changes may cure, to some extent, the simulator sickness problem. We may be losing something for transfer training. Anytime we're doing research in this area we need to be thinking about the implications for transfer.

DR. PARKER: But those studies are being undertaken to characterize the nature of the conflict which produces simulator sickness. If you know that, if you can say, "This is not a problem, but this seems to be more a major problem in terms of producing errors," then whatever metric you are using to evaluate the alteration of the stimulus, then presumably you are in a better position to design a better simulator downstream.

10. Experimental Approaches To Simulator Sickness

10.1 Parker: Study Motion Base And Visual System Using Target Acquisition

DR. PARKER: I also wanted to restate something I suggested earlier as a potential study, if not a project you'd want to pursue for applied purposes, and that concerns production of moving-base frequencies and visual-surround frequencies which might be most nauseogenic. And an experiment I can conceive of doing, but wouldn't want to undertake, would involve using the paradigm of active head motion to a randomly-displaced target, for the subject to look straight ahead and the target appears, the subject moves his head to that target. Procedures are readily available for measuring the error signal.

You could take that paradigm and, prior to the active head motion, move the base on which the person is sitting and study the frequency characteristics of the moving base, which produce errors in the acquisition of the target. Similarly, you could take a surround and drive the visual scene and study the characteristics in terms of frequency or velocity, I guess is the better measure, that produce errors in the acquisition of the target. Without having thought it through carefully, I d predict that where you're getting a break or a crossover between primary visual control and primary vestibular control is the frequency at which you would find the most conflict and subsequently the greatest sickness. I don't know that.

DR. KENNEDY: It's certainly something that's close to being doable in the way that VTRS is presently configured. And maybe with some additional changes it might be part of the area of interest where it could be done.

DR. PARKER: I'd appreciate any feedback from your people after you've had a chance to think bout what's happened here this past week on how we might best proceed in trying to develop a preflight adaptation simulator that would in fact produce motion sickness. That's not the major problem, but would produce the kinds of adaptive changes in VOR and sensorimotor perception we're after.

10.2 Invitation To Meet With Chambers At Orlando

DR. KENNEDY: As we start to tie up things, it would be useful to have you plan on a meeting in Orlando. And ask Walt to put you in touch with some of the other people.

DR. PARKER: I would very much like that.

DR. KENNEDY: A thing which is not an inherent part of our charter, but is going to come out of this gathering, because we have been encouraged in this way, there may be specific experiments that could be proposed, some of which may be very simple and they may be doable in the visual technology research simulator, which is a research tool specifically designed to put up all kinds of visual and inertial combinations for the purposes of evaluation for future simulator design.

10.3 Young: A Series Of Univariate Studies Using Multi-axial Stimulation

DR. YOUNG: It seems to me on the one extreme developing experimental paradigms that show how visual/vestibular conflict can lead to motion sickness have been worked out and have been done fairly nicely by at least three different groups in the literature. If one wants to pursue that, we should go back to the rotating drums. They have not dealt largely with such things as relevancy to simulator sickness, active/passive, past history, level of experience and so on.

I believe that the major thrust of a recommendation should not be a basic research program on motion sickness. It should be what do we have that is inherent in simulators that leads to simulator sickness. Given the difficulty that when you do an experiment to simulate it, only a small percentage, 10 to 50 percent, are going to experience sickness in a rotating drum.

So I think that the appropriate tool is a flexible state-of-the-art simulator for exploring the effects on simulator sickness, field of view, content of the visual scene, dynamic lags, motion extent, control stick sensitivity. I think the approach should be a multi-dimensional study in which one dimension at a time--you explore what the result in fact is of reducing field of view, reducing picture content, increasing dynamic lag and so forth.

DR. KENNEDY: So unidimensional studies with multi-axle stimulation.

DR. YOUNG: Right, we don't really have the facts, but we have a lot of very reasonable theories. And I think you have to do them with a realistic simulator with a class of pilots.

11. Dr. Young's Notes: Vestibular Masking, Soft Freeze, Flashbacks, Motion/No Motion Studies, Viewing From Outside The Design Eye, Sign Error Distortions Are The Most Serious, Maintaining Visual System Alignment

DR. DUNLAP: Let him go through the things he's really got marked down there and he's thought about and let's get them down and get back to questions.

DR. YOUNG: On the vestibular masking issue, question 9, I think that just adding random noise is probably not going to work on vestibular masking, I think that the idea of appropriate use of a soft stop to fade before freeze on the visual is a very reasonable thing to do.

Question 11 about restriction on flying, I'm aware of the military experience. I have never found any evidence in commercial of flashback.

Question 15 about the motion/no motion issue on transfer of training, this is really for the record. I don't think that those studies were properly done and they each had an unfortunate effect of casting doubt on the whole value of motion/no motion simulators for training. Sitting forward of the design eye is indeed a problem, and I've had many people comment to me on the fact that when they are in a position in which they are not exactly lined up with their individual appropriate video display, it's upsetting. I've heard comments that they kept looking over at their first officer's display to see what was going on on that side of the runway. That gets some incidence of simulator sickness.

DR. KENNEDY: I sat in on a preproposal briefing that was attended by major simulator manufacturers, and the navy was presenting some of its requirements, one of which was for landing craft air cushion. And it was to have crew members seated abreast. They would be physically abreast in the simulator to operate this air-cushion vehicle. And they wanted less than 4 percent distortion. And they implied that they wanted a wide field of view dome as their display medium. The dome would have to be perhaps 100 feet away to achieve 4 percent distortion for all three seated-abreast operators, unless you used mirrors or something else. And is 4 percent bad from a conflict theory standpoint? Is this something that we ought to start pursuing?

DR. YOUNG: I think we have to pursue some ways of quantitating conflict. I have no idea where the 4 percent comes from; whether it's too big or too small. I somehow doubt that anybody else can, but I think that that's an area we should pursue. How much distortion is tolerable? I'll give the only guideline that I'm confident of distortions which involve a sign error are more serious than merely a magnitude error; much more.

DR. KENNEDY: But the sign could be velocity as opposed to just displacement.

DR. YOUNG: Usually velocity. I don't think that displacement is nearly that much of a problem as it was. After all, you should always set your seat height at the same position. You probably can go from airplane to airplane with different positions of the seat and do a reasonable job. But thinking that you are level when the visual field makes you believe that you're sinking, or vice versa, is a disturbing occurrence.

DR. KENNEDY: What about maintenance checks of line-up alignment? Is this something that can go out of tune?

DR. YOUNG: I'm told that it is; that maintenance, even on digital systems, that it is a serious problem in both the military and commercial fields. It is one that is largely disregarded.

DR. KENNEDY: Are there recommendations that we could make that don't have anything to do with a clear-cut idea on simulator sickness, but which would be something that someone might listen to, possibly because they would be able to be implemented? Like, could we propose that a team be formed to go to all these places to do all this stuff, to check it out and have it be routine because we don't know what we've got since we can't tell you what stimulus is? Is that a recommendation that could be done?

DR. YOUNG: I guess I would not make that a recommendation because I think that the same team that became very good at fixing a given simulator in Orlando will probably be inept for quite a while, when they went to NASA-Ames to do it out there, let along a commercial simulator.

So I think that has to be taken care of in each facility; or, better yet, if it's not a research simulator but a commercially-generated one, that that be a part of the maintenance contract that's sold with the simulator.

DR. MCCAULEY: You'd probably have to generate some criteria for calibration.

DR. YOUNG: But there are acceptance criteria that go with the purchase of a new system. I'm told that it is a problem, that a simulator is accepted, meets this criteria, and nobody ever checks it again and somebody comes back sometime later and says, "Gee, this isn't right. Let's check it," and finds that it's way off.

"How did it happen?" "Oh, when this other pilot came in last month he said we had too much yaw, so we changed the gain." And it was never documented, by the way.

12. Helmet Mounted Display

DR. YOUNG: I want to just bring up the topic of the relationship of area of interest displacement. I don't have anything to contribute, but I'd like to hear what the status of that is.

12.1 Introduction: Head-And-Eye Slaving, The Area Of Interest

DR. BERBAUM: Okay. The new helmet-mounted devices can be typically operated in two modes: head-slaved and eye-slaved.

With head slaving gets you out of the problem of servo positioning the projector, but also requires that the scene update rate have a similar rapidity. You may have scene movements with the head, initially, and then perhaps refractions.

DR. YOUNG: Are you talking about the helmet-mounted?

DR. BERBAUM: Helmet-mounted, yes, in the head-slaved mode. Will this produce vection stimulus and so be especially disconcerting? If not, will recalibration of VOR occur. With adaptation such effects would be mitigated, but what happens when you leave the simulator? You are going to need to be recalibrated?

DR. YOUNG: And this is all attributable to the delays inherent in the update of a CIG?

DR. BERBAUM: Yes.

DR. YOUNG: Could I ask if this is something that has been observed in all of the head-slaved devices; and what kind of lags?

DR. BERBAUM: It's hard to answer your question because we don't have enough good data yet to know the extent of such problems. We know that there will be some displacement of the scene. It's not necessarily a big problem.

DR. YOUNG: Just talking about the area of interest, there will be a delay--in addition to the field being delayed--until it catches up with the helmet if you are displaying it. All the field is going to move with the helmet until it gets recalibrated and gets put back where it belongs.

In addition to that problem, which I see as probably the most serious, there is also the potential that the area of interest is going to be in the wrong place for cues, because the area of interest is always going to be in the middle of the helmet, not where the eyeball is looking necessarily. I'm questioning whether, since we know that the VOR is trying to stabilize the eye in space, you'll frequently get the condition where the head-and-eye orientation in space are fairly different, including a substantial offset at the end of a head movement. The result of which is that in a head-position driven, area-of-interest display, you will get a situation in which suddenly the high resolution inset is not where you're looking.

And my question, therefore, is whether that factor, in itself, is found to be either disturbing perpetually or producing simulator sickness.

DR. BERBAUM: So far we don't have much information. The only people who we have information from have been a couple of the engineers who haven't seen all the conditions. Walt (Chambers) said yesterday that sometimes these systems lose track and suddenly your area of interest pops up way over here (indicating) and you can't get it back. But we really just don't know.

DR. PARKER: Working with the helmet-displays at Wright-Patterson, one of the conditions of the experiment that we were performing was we tried to have the computer-generated room appear as it would in a natural environment, to get an update rate that was reducing room jiggle as you moved your head. And part of our paradigm was to continue this active head motion with rest intervals in order to get an update rate that would reduce jiggle. We had to use a very sparse visual display with a 28 millisecond update rate. We were still getting perceptual jiggle. And that jiggle disturbs the apparent solidness of the room walls.

DR. YOUNG: If it's a total-system delay from head movement pick-up through the CIG of only 28 milliseconds, I'm amazed it had a--

DR. PARKER: 28 mil was the scene generation.

DR. KENNEDY: All by itself?

DR. PARKER: All by itself. And the other part is unknown, or it's unknown to me.

DR. YOUNG: Okay.

DR. PARKER: We were hoping to use the scene generator that Johnson built for NASA to produce a simulator for the flight adaption training. And we ran into exactly that problem you did, which is a scene generator that works in the hundred millisecond range.

DR. YOUNG: What about the second mode, the eye movement area?

DR. BERBAUM: When I say two modes of operation, that applies to the one that is going to be implemented at VTRS. You have to remember that the same notion is getting implemented in several places, and have different capabilities. For example, at Wright-Patterson they have binocular disparity that has a component which does not exist at VTRS. A second mode that will exist at VTRS is eye-slaved with the area of interest still tacked to the center of the background field. So you may have the scene moving with an eye movement.

If you had a configuration that was a combination of the background field following the head motion, and the area of interest following eye-movement, then your ability to fix problems resulting from eye-movement would be substantially enhanced. If you solve the problems with the background field and its movement, then you can fade in the area of interest when you can put it in in a reasonable way. For example, one of the difficulties with an area of interest display is that because of the high detail, if that thing moves around in the scene, things are going to pop into existence. Objects are going to suddenly be there that weren't there before. You can mitigate this to a certain extent by having a contrast-blend region. And you could also temporarally blend the area of interest on and off into those conditions where you would expect some rather peculiar things to happen. Maybe it makes more sense to fade and bring it back when gaze stabilized. But in the VTRS simulator what we will have, apparently, is an area of interest that's tacked into the center of the background field with both channels moving with either head or eye movement.

DR. YOUNG: What you're saying is that there is not yet any experience accumulated with the eye-slaved to indicate--

DR. BERBAUM: Right. I think most of the concerns at this point are interpolations from the laboratory.

12.2 Contingent Adaptation

DR. WELSH: So a big concern of yours is the possibility that some of these problems that may occur in the laboratory for those pilots will also recur when those pilots get into the airplane, that it might have some of the same adaptations inappropriately showing up?

DR. BERBAUM: Yes. I guess it depends on what it is that gets recalibrated - how you think adaptation works. If adaptation is only the previous few minutes' history, which is just recalibrating some set points, then surely you can dispense with any fears about it.

DR. WELSH: But supposedly not that, that it could come a month later, if the situation were right. The question is to what extent some of the other aspects of the situations are very similar, between the simulator situation and the cockpit. I mean, if there are enough salient other cues already in a live environment, then it seems at least if you have a person that is sometimes flying a plane or sometimes a simulator and they jump back and forth that like the deep sea diver--

DR. BERBAUM: You need a discriminative stimulus.

DR. WELSH: Yes, you need a discriminative stimulus, but I'm sure that it must be that you could develop those two separate behaviors and they wouldn't interfere with each other.

DR. BERBAUM: The strategy now is not to. It is to build in complete realism and fidelity.

DR. WELSH: Yes, right, but it sounds like some of that stuff is almost impossible now to have no delays whatsoever; for example, to have a totally instantaneous change in the scene with the head movement. I don't know much about it, but it sound like you're saying the way things are now that it's pretty much impossible to reduce that down to zero.

12.3 Helmet Sickness

DR. EBENHOLTZ: No one has helmet sickness yet, but it's coming.

DR. DUNLAP: It's an anticipated disease. We can anticipate that difficulties will arise whenever you substantially change the simulator. And we can even guess at some of those things, but we won't know the full impact of them until this actually comes on line.

DR. YOUNG: I was only going to comment, I think we're starting to see that as we get to more and more helmet-forged skies, helmet-mounted viewing devices, we are beginning to see more problems that involve sickness, not necessarily simulator sickness. And maybe we'll call it helmet sickness, but I believe with the newer generation of night-flying and in an attempt to superimpose nongeometric symbology and visual information on the scene, we're looking for trouble. And I think the issue which has been explored for a long time of the helmet-mounted, heads-up display and how to stabilize it in an environment--

DR. MCCAULEY: That will be part of the system that is planned for NASA-Ames for the LHX simulator. They will have monocular, high-resolution, effectively heads-up display right smack in the middle.

12.4 Eye-Slaving Versus Head-Slaving: Problems With Head-Slaving

DR. BERBAUM: What kinds of effects would you expect to occur, particularly with the area of interest in the eye-coupled version of it, as opposed to the head-mounted?

DR. YOUNG: I think the eye-coupled version will have fewer problems than the head-coupled because you will not have to worry about the presence of a high-resolution inset that is not at the fixation.

The problem with the head only is that you notice there's a search light shining on the scene, but not where you're looking. So there's a tendency to, I believe, have this higher-level kind of rivalry between where you're currently fixated, which is presumably the result of an intentional saccade, and where the simulator thinks you ought to be looking, which is right down your nose. And that, consequently, has got the highest resolution area.

Your peripheral vision is good enough to notice that there's more detail--if you are looking off to the side and your high resolution area is right in front of you, the peripheral vision is going to say, "Hey, take a peek at that." And I see that as being difficult.

DR. MCCAULEY: I think people will be able to learn to perform well under those conditions.

DR. YOUNG: But that's not the point of simulation.

DR. MCCAULEY: That's right. But then you have a problem with transfer training.

DR. YOUNG: You learn to perform well by avoiding large eye deviation.

DR. MCCAULEY: Like a coal miner with the light on his head, instead of the making eye movements he's got to turn that light.

DR. YOUNG: That's right. Since it's not the strategy you use in air combat, I think it's not a sensible one to pursue. The very kinds of simulations that we are talking about are not the benign commercial pilot where his entire head movement consists of looking from straight ahead to 20 degrees down and back straight ahead, but the air-to-air combat, around, up and continuously to try to find friend or foe.

DR. BERBAUM: You have a certain advantage of saccadic suppression with eye slaving, giving you some tolerance allowing you to look at the scene, but it is not complete.

CHAPTER VIII

Discussion with Robert Welch, Ph.D.
September 27, 1985 - Afternoon Session

1. Introduction to Dr. Welch's Research

DR. DUNLAP: Maybe we can start with a brief description of Dr. Welch's interests and backgrounds for the record.

DR. WELCH: My area of interest has been most generally intrasensory organization, and more specifically examining situations which involve conflicts between sensory modalities or between sensation and motor control. This includes most prominently research on adaptation to distorted vision produced by wearing goggles that displace, tilt, or reverse the visual field. I study both the immediate response to conflicts, which is frequently referred to as intrasensory bias, where one modality almost instantaneously brings the other one more or less in alignment with the first. Secondly, long-term response which I refer to as adaptation which involves a longer period of time and usually a lot of active interaction with the environment.

I think a lot of stuff I've done or thought about has relevance to motion sickness, particularly when you talk about a conflict theory, which I generally hold to in regards to adaptation to distorted vision. One of the aspects of my research is to demonstrate which modality will be the more powerful one in a situation depends on what the task is. There has been a tendency to talk about vision as being a dominating modality. I think that's only when you're talking about spatial tasks. There are other tasks in which vision may actually be a rather variable modality; in particular, tasks involving temporal perception, temporal rate.

2. Does More Conflict Lead to More Sickness?

DR. WELCH: I went through the larger series of questions and came up with ten that seemed to be ones that I could talk about reasonably well. I want to go through those and give you my thoughts.

Question number 1, about the conflict theory and whether that implies the greater the conflict the more the sickness. In contrast to what Larry said, there is some work that indicates that that can't be completely true, because 0.2 Hertz is some kind of optimal rate suggesting an optimal amount of conflict. Also, there are some conflicts that don't seem to produce any kind of motion sickness at all. Apparently, things like riding horses or motorcycles do not produce any kind of motion sickness.

DR. YOUNG: There is camel sickness.

2.1 Vestibular/Visual vs Visual/Visual Conflict

DR. WELCH: Of course, any conflict that doesn't involve the vestibular sense -- you've got to limit it to those particular kinds of conflicts rather than conflicts in general. There's all kinds of stuff with vision and proprioception conflict.

DR. YOUNG: When you say involve vestibular sense, I assume you mean even though the vestibular system may not stimulated.

DR. WELCH: Yes, that's right.

DR. MCCAULEY: How about if we state it in terms of spatial information about one's orientation and movement through space? Then it's even more general. Conflicts in that area could produce sickness. There are all kinds of other sensory conflicts that don't have to do with spatial position that don't result in sickness.

DR. KENNEDY: Crampton's of the opinion that if you had a true visual/visual conflict under the right circumstances you could produce sickness, but it may be necessary to have a labyrinth. He also thinks that with the right kind of visual/visual, even in the absence of a labyrinth, that motion sickness can be produced. I can imagine a binocular and a monocular cue to depth being put in that position.

DR. WELCH: They've done that. It doesn't produce nausea. Sickness occurs where something visual occurs and there should have been a vestibular stimulus and there wasn't.

DR. YOUNG: I agree with you. We find some percentage of subjects get sensations of vertigo and sometimes motion sickness just looking at a pure roll display. But the conflict there is visual.

DR. EBENHOLTZ: Well, then we've got to come to an agreement on what constitutes a visual/visual, since just about every visual will entail that type of conflict.

DR. WELCH: If it's between two different depth cues or even contradictory information, that does sound like visual/visual, but certainly not one I could imagine producing any nausea.

DR. YOUNG: I know of two cases that have been explored; one that I tried where we had yaw vection, continuous circular vection, and then the subject was always stationary and would just change the plane of rotation. I was trying to produce a completely pseudo-Coriolis effect and that failed, and did not get any motion sickness.

Another that I have not done myself but has been reported by others, if you use stroboscopic illumination you get an ambiguous field movement. It can appear to move in either direction, and sometimes you get optokinetic nystagmus on the left and sometimes on the right and sometimes in both directions. I've never heard anyone talking about any motion sickness stimuli, even as you flick back and forth between directions.

DR. DUNLAP: In the absence of a contradictory demonstration, I think maybe we can sharpen the theory to call it vestibular conflict.

DR. WELCH: You mean just vestibular?

DR. DUNLAP: Vestibular conflict.

DR. WELCH: It has to conflict with something.

DR. DUNLAP: Vestibular conflicting with vestibular, or with visual, or with audition. I bet that as long as there's conflict that involves vestibular with something, that's where it is.

DR. BERBAUM: If we say we're only talking about conflicts occurring in the vestibular nuclei, I think we could be correct. Those conflicts that get resolved in other places produce no sickness. For example, binocular disparity versus monocular cues to depth as in Gregory's inside-out face produces no motion sickness.

DR. WELCH: But if you're not moving, then it seems the vestibular isn't even involved in the situation.

DR. EBENHOLTZ: It is involved in virtually everything. There is a vergence input. We know that you modulate the VOR by changing convergence. I wouldn't be surprised if accommodation also has an input into the VOR. So I think one may be very hard pressed to find visual stimuli that don't wind up having some impact through the vestibular nucleus.

DR. WELCH: My guess is that that is such a removed impact, that those situations wouldn't produce much nausea as long as you weren't moving around, just viewing it.

DR. EBENHOLTZ: Let me describe one case. If you have a flow field that's an expansion field with dots coming out from center peripheral, that will induce vection, translation vection, and motion sickness.

DR. WELCH: Yes, but that's such an obvious cue for motion, of bodily motion, that it enlists this conflict, I presume, with lack of vestibular sensory.

3. Measuring the Magnitude of Conflict

DR. WELCH: Question number 2 seems to be an important one about measuring the magnitude of conflict. If a conflict theory is going to keep from being circular, we have got to be able to measure conflict independent of the outcome.

In my research area, we get separate measures of each modality that we assume is involved in the conflict. This is a possible way of quantifying conflicts. I have a sort of everyday example. You are inside a rocking boat. You're below deck and looking at the wall. Gravity is telling you you're rocking, your vision says nothing is happening. Initially, when you are first put into the situation, measure your moment-to-moment perception of the change of gravity. Then taking gravity away--which I don't know how to do- but assuming there wasn't any change in the visual relationship at that part, that the difference between those two represents an index of the size of the discrepancy, but not only the difference between the mean vestibular measure and the mean visual measure, but also the variability from trial to trial on a given measure has to be taken because of differences of precision of different modalities.

So, for example, if I was going to measure the discrepancy between vision and proprioception, where I see my hand and where I feel it to be, I'd want to get not only the mean of a bunch of trials on each of those, but also a deviation for each of those. That could make a big difference if one was a very imprecise modality and you get a very spread-out distribution, and another is really sharp. That's a different kind of discrepancy than two sharp distributions would be, even though the means were the same distance from each other. Consequently, the index would not be the pure distance between these peaks, but would be in terms of the average standard deviation of the two distributions, or something like that. That would take into consideration the precision of each.

So it seems to me that, given whatever situations you want to use to create motion sickness, you need to analyze it and say, "Okay, what's the presumed conflict." The presumed conflict here is between vision and some aspect of inertial perception. Get the pure measures of each one alone, by itself, plus the standard deviation of trial-to-trial responses of a given subject and take the distance in terms of the average standard deviation of these two distributions. It might differ from person to person, so you would want to do it individually. The same physical discrepancy might be perceived as a different size discrepancy from one person to the next. It seems to me you could relate that to incidence of motion sickness. And I think unless you do something like go in and actually measure these things, the conflict theory really is circular and self-verifying.

DR. KENNEDY: What about using the exponents for the different sensory dimensions as a starting place, call those more sensitive that have steeper slopes.

DR. WELCH: Like magnitude estimates?

DR. KENNEDY: Yes, take the exponents and use that as a slope. Use that as a starting point in that domain that has the least amount of energy necessary for the stimulus and then use Just Noticeable Difference as a secondary to determine sensitivity.

DR. WELCH: I suppose that's possible. It seems to me that your best bet would be to go into the situation right there and measure what represents accuracy and precision, the average response and the variability from trial to trial for that given subject. That seems to be getting closer to the real phenomenon. Intrasensory bias research would measure where your hand is without vision, and where you see your hand. So you get visual locus through a prism which is displaced, and the felt position of the hand which is not displaced, and then take the difference between those two. That represents the perceived discrepancy that we assume exists when both of them are present.

DR. BERBAUM: And so the corollary to this in a simulator would be to have pilots fly a series of maneuvers, vision off, and have them fly motion off.

DR. WELCH: Something like that, right. And then assume the difference between those two is what exists during the time that both of them are present. That is the discrepancy they are being faced with, that they have to deal with.

DR. YOUNG: We've done a series of experiments which involve a pointer that you would point toward the center of the earth and do it with different kinds of motion cues in a simulator. Also, we vary the visual cues. We never carried it to the extreme that you are suggesting, which seems if you go and turn off one entirely to see what the person does. I'm afraid that with turning off the motion entirely it would be easy to just always point the pointer toward your feet unless you put in--ran some disturbance.

DR. WELCH: You're not asking them to point down when you've cut motion. That part I'm not quite sure how to measure, but you're measuring the lack of change of the visual environment relative to your body that I assume occurs to a person.

DR. BERBAUM: I see a difficulty. Supposing pilots flew through just the visual and then just the inertial presentations, and produced exactly the same route, speeds, et cetera, so that spatially their results are very good. But now you introduce both together where one cue is delayed behind the other. It begs the question of space or time kinds of measures of conflict.

DR. WELCH: If there's a time delay there's automatically a space delay, or automatically a loss of constancy of visual position because it means that you moved and something didn't move for just a moment, and then it did. So for just that moment while it was delayed, it's apparently moving perceptually. Like it stayed with you for just a moment and then it fell behind like it's supposed to. So it's a limited period of time for this discrepancy, but somehow during that period of time is the thing that needs to be picked up, the discrepancy that exists there. Now, I haven't even addressed the practical application of how this would really work. I'm just trying to take from the research I'm familiar with that I've done and see if what we do could be plugged into the area. And maybe it's not practical.

DR. BERBAUM: You could get a spatial signature for each as a function of time, and they might be identical, but shifted.

4. Adapting to Temporal Delays and Cue Asynchronies

DR. WELCH: There is another aspect of this question. Does temporal rearrangement have the same distributive nature as spatial? And I think we just sort of said that. I don't think you really adjust the temporal rearrangement. You have a temporal delay of a spatial stimulus, so that's really what it means. And I think that resolves down to illusory motion of the visual field. So it really is just another way of creating it by putting a delay. That's just another way to lose visual precision. Held and Goldsmith did a study in which they interjected several different delays, and they found that 300 milliseconds or more of a delay is too much for the system to adapt to.

DR. KENNEDY: There is a simulator with a 350 millisecond asynchrony.

DR. WELCH: I'd like to make the suggestion that that number shouldn't be taken as being a golden number of some sort, because the studies that have involved delays have also involved a single point of light, not a whole visual field. I have a hunch that the actual delay that we can tolerate may be a lot less than if we have a whole visual field.

DR. KENNEDY: I think that's a good point. We were thinking that 300 with no adaptation, that's a good number to say anything more than that is terrible.

DR. WELCH: We're so much more sensitive to changes of whole pattern of field than just a single dot in the dark. That's also undoubtedly the reason why they don't report any nausea produced in either Held's study or in Wallach's work. What they've done in those studies is the subject's head movements, say from left to right, cause a point of light to move up and down in an otherwise dark field, or vice versa, and in the opposite direction, but also orthogonal to the head movements. And people react to that dramatically, but you never heard any reports of nausea when you read these studies. Whereas I just know that if a whole visual field did that, I'm sure you would have reports of nausea. I think it's very crucial in going from those simulators that you pay attention to that.

Also, the fact that a small point of light doesn't produce nausea relates to the notion of how different people react to the simulator, starting off with a small visual field and working up. That point of light is the smallest visual field you can imagine, and that is what some of these guys have been using.

5. Adaptation vs Habituation: Adaptation Won't Resolve the Conflict

DR. WELCH: An item I wanted to cover before Shelly (Ebenholtz) left, because I think he might have some things to say about it, is item 31 which is how to reduce the perceived magnitude of a conflict, and that it should be regular rather than changing from moment to moment. Could you adapt more easily to something that's regular rather than changing? The simple answer to that is: All the data on adaptation to distorted vision would suggest that, yes, indeed, you would want it to be a stable kind of conflict, one that wasn't changing, if you want to get adaptation to occur as quickly as possible.

The next most difficult thing to adapt to would be a situation that was changing, but changing in a regular fashion over time. And the most difficult thing to adapt to ought to be one that is really random, where you can't find any relationship to what is happening.

DR. KENNEDY: Do you think you can adapt to that at all?

DR. WELCH: Yes, in a sense. But let me get to what I was going to say here. The main point of this response is, we're talking about conflict as a likely cause of motion sickness, and then adaptation as being something you go do that leads you to not be motion sick any more. If you just take that directly out of the research that I'm familiar with, that would suggest that there's some kind of resolution of the conflict, and when it's resolved you're not sick, or you aren't perceiving it anymore. And I would be surprised if there were a real resolution of the conflict in terms of recalibration.

Remember how I talked about how we could measure each modality separately and that would be a quantitative measure of the discrepancy? Well, let's say you took that measure at the very beginning, when you first put the person in a situation that is nauseogenic, then they get sick, and get sick, and all that stuff, but then after a while they aren't so sick and then they finally get over it, let's say. Then you measure the discrepancy again at the end, and you measure with two different modalities individually. If there is really a resolution of the conflict it would mean that the discrepancies wouldn't come up with a big difference anymore. That is, the visual and the gravitational measures would come up being relatively similar to each other, either one would be pulled over to the other--the first would be pulled over to the second or the second to the first--or they would both sort of meet in the middle somewhere.

But I bet that wouldn't happen. I don't think you'd find that. I think that if you measured individually the visual relationship to your body and the gravitational separately at the end of the period, you'd still find them separate from each other. The discrepancy would still exist, the conflict, but you are not reacting to it in an adverse way anymore. So I don't think you get adaptation--that's my guess. I mean I really don't know the data on this, but that would be a testable question. My guess is that you don't get one modality recalibrated in terms of the other, or some median in the middle situation, so that wouldn't be adaptation in terms of a resolution of perceptual modification.

What I would suspect happens is that people simply get used to having a conflict. In other words, the conflict no longer surprises them anymore, so maybe you could say that's no longer a conflict, if you wanted to, but not by my quantitative measure. The conflicts quantitatively would still be there, but pilots might be now expecting it; that is, it's something they're used to having. It's like people wearing reversing goggles, at the end of wearing them for 25 days the world still looks upside down, but they expect it to look upside down. See? That's the difference. And so I use the term habituation. And some of this is stuff that Shelly has talked about at one point or another.

In terms of adaptation to tilt, there's a sort of getting used to that kind of situation. Here's how I would suggest that you could measure that hypothesis. The habituation is getting used to a constant conflict and therefore not being made sick by it. It means you now expect it to occur. What it means is that if you have a vestibular input you expect a certain visual outcome to occur from it; the one that actually does occur, now, not what you expect when you first wear reversing goggles in a situation, now that you've been in it you expect that.

5.1 Measuring Habituation

DR. WELCH: It seems like you'd measure that by get[illegible] alone, without any vision, and asking the subje[illegible] outcome of that would be, or vice versa; give [illegible]

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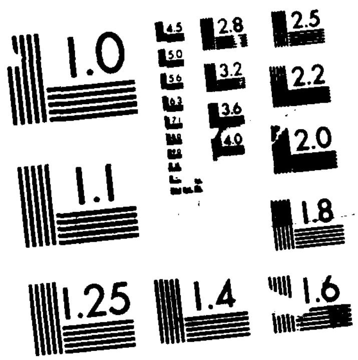

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predict what the gravitational input would be, by some kind of a measure. And they should be really good at that at the end of this period of time, whereas they would be lousy at predicting the input at the beginning.

That would be the way you'd measure the change that was taking place, not in terms of a resolution of a conflict, because I think that would not happen. But no longer being surprised by the outcome of the recorrelation kind of thing would be a way of measuring this phenomenon, instead of saying, "Here's this. What would you expect the visual to do?" And they could either do it very accurately or with a shorter reaction time than they did before or something.

DR. DUNLAP: You could learn that it's still weird but not poisonous.

DR. WELCH: It's weird but not surprising anymore. It's an accustomed weirdness, if you will.

DR. KENNEDY: If it were sufficiently weird that you could not adapt to it as in performing better, that doesn't mean you could not adapt to it as in not getting sick.

DR. WELCH: I would also suggest that you probably could perform better, as well. What it doesn't indicate is that you no longer perceive a conflict. You do, by this idea, still perceive a conflict is there, but there's a difference between the two. But you expect it to be that way.

DR. KENNEDY: And there may be some conflicts that are sufficiently close together so that you can bring them into line.

DR. WELCH: Yes, there are, and there may be some change here, but I bet that the changes we're talking about are too big to be handled by a perceptual resolution. That's my hunch. So I use the term habituation for that kind of thing, getting used to a conflict. An adaptation I reserve only when there really is a shift of one modality to the other, where if you measure them individually now you get different values than you did when you measured them at the beginning.

DR. DUNLAP: A new set point, in Shelly's terms.

DR. WELCH: Yes.

5.2 The Role of Expectancy

DR. EBENHOLTZ: It's hard to map into the two approaches, because from my approach, perception falls out, not as a cause of anything, but as an end result of shifts in physiologic states or in system set points, so that it really is not your perception. Your common knowledge is not really playing a role in the casual sequence. And I remain equally skeptical about expectation, because expectations are themselves driven by things; although I'm sure there is some top-down activity, so I can't be the total arch-behaviorist or physiological reductionist because I know we have a cortex and it's driving some stuff. But I guess my role is to try to be the skeptic here and say, yes, okay, we'll buy that if we have to. I don't know if we've exhausted all other possibilities and basic mechanisms.

DR. WELCH: That may well be true, but it may still be that this change in expectancy is at least a correlate of what's happening, if not causal. And if it is a correlate, it still could be useful in terms of measuring what progress a person is showing. So it doesn't bother me one way or another in terms of my outlook. A test of whether it's causal or not would be to manipulate a person's expectancies in another way. If they overcame being nauseated more rapidly, then I'd have some evidence that it may be an actual causal variable rather than just an artifact or side-effect of some other process.

Anyhow, I was laboring to figure it out. Conflict sounds like what I do. Adaptation sounds like what I found. But when I started analyzing it, I had the feeling that you wouldn't really find the kind of changes that we find. We find shifts in position of the arm, everybody does that stuff. You see your hand displaced over to one side, and after a while you feel like it's over there. And vision moves a little bit, too. Sometimes they just meet in the middle and there's no conflict at all. Well, maybe that's true in some of the kind of situations you folks are working with, but I bet you some of them are just too big a conflict for that to happen. But something else happens that takes care of the problem.

DR. BERBAUM: So habituation is a resolution of conflict between the expected and current input.

DR. WELCH: Right.

DR. BERBAUM: Whereas intramodality conflict can still be present.

DR. WELCH: Yes, that's the idea.

DR. EBENHOLTZ: Just one possibility here, and that is that to a certain extent expectation also brings with it a change in arousal state. So there's another brain mechanism there that may come to play a role.

6. Adaptation as a Cure for Simulator Sickness

6.1 Which Modality is Recalibrated

DR. WELCH: I just wanted to maybe get in one more topic before Shelly has to leave. One question here is, "Would adaptation be more likely to occur in conditions where vision correctly is interpreting reality or the converse?" Well, vision is the dominant sense in spatial tasks, but doesn't seem to be in temporal tasks, so we have to limit it to that. As far as the second part of the question regarding reality, I think it's absolutely irrelevant to talk of what's reality or not, which modality is speaking to reality. For example, if you look at all the adaptation literature, the changes that are taking place are not in the nonveridical sense, which is vision. It is in the veridical sense. That's the one that's getting modified. Felt limb position is shifting, felt eye position is shifting toward the incorrect visual information.

The net result is correct performance, accurate, real-life performance. But which modality does the shifting doesn't seem to have anything to do with which one is telling you the truth. It is whichever one is more malleable than the other. And so proprioception is easier seen to be more changeable from purely visual information. So I don't think you need to talk about which one is telling you reality or not.

You can shift what one modality will change by attentional factors; not just general attention, but attention to a specific modality. If you pay a lot of attention to proprioception, you can make vision shift in the direction of proprioception. But apparently we have a normal tendency to attend to some modalities more than others, and normally seem to pay a lot of attention to visual information. Now, I don't know what relevance that has to simulators, but it's conceivable that it could shift attention to more on gravitational cues or something that might have some beneficial effect, away from visual information.

DR. MCCAULEY: One thing that impresses me is that a lot of your extra sources of information, such as the G-seat, and all those kinds of things, I believe are extraneous. I think they are totally ignored.

6.2 Contingent Adaptation: Simultaneous Adaptation to the Simulator and the Aircraft

DR. WELCH: One question asked, "It may be possible to adapt to two or more perceptual worlds simultaneously. Do you have an opinion as to whether this is a good way to solve the simulator sickness problem or not?"

I want to ask a question: Are you still defining simulator sickness as that sickness which is caused above and beyond what would be caused by the actual planes you're simulating? If it just simulates sickness you would get somewhere else, that's okay.

DR. KENNEDY: When questioned or when trying to make a point, we've suggested that we know that sickness occurs in airplanes doing certain sorts of things. Were that to happen in a simulator, we'd say that's air sickness properly simulated.

DR. MCCAULEY: It also happens in different people, different populations. Generally the students without much experience are the ones who get sick in the aircraft and the instructor pilots, test pilots with high flight time are the ones who get sick in the simulator ordinarily.

DR. WELCH: Well, that's germane. It's a question of whether or not it's important to get rid of the motion sickness in simulators, actual true simulator sickness or not. But let me back up just a bit. The question about whether you could adapt to two or more perceptual worlds, yes, I think you can. I think you don't have the evidence for it, the deep-sea divers stuff where people can immediately put on the face mask and be okay in the water or take it off and not have negative aftereffects leaving it off.

There's no reason to believe that that wouldn't also occur in the same kind of situation of going from a simulator to outside of it, into it or out of it, or from a simulator to the airplane and back again. But you have to do that enough times to build up this kind of distinction that they could make. And that might be a way, with repeated experience, of getting them ultimately to be able to be adjusted to both different environments, although even then you'd probably want to do this in gradual increments to, say, the size of the visual field and the simulator and things that have already been suggested, on top of this. But I think you could expect if you are moving a person back and forth between these two worlds you would get this building up of a discrimination.

MR. WILKES: You say two worlds being different, but they're consistently different.

DR. WELCH: Yes.

MR. WILKES: No problem with any kind of expectancy overlapping from one--

DR. WELCH: There are at least some salient discrimination cues that allow you to identify which environment you're in and whatever the adaptive mechanism is that turns on or off. So there may be some initial negative transfers but ultimately that should disappear.

6.3 The Paradox: Is Adaptation to the Simulator Good or Bad?

DR. WELCH: But a more basic question is how important it is to get rid of the motion sickness, the simulator sickness, in the first place. Do you think that a person can have simulator sickness and yet still be learning things in a simulator that are useful in the plane?

DR. KENNEDY: Sure. I don't think that simulator sickness enjoins one from learning, but I wouldn't be surprised if it doesn't compete for his functional resources. If he's paying attention to how he feels, I wouldn't be surprised if he learned less.

DR. WELCH: Sometimes you've said things like, well, maybe we don't want people to adapt to simulator sickness because that's maladaptation. Because obviously the simulator must be doing something that isn't the same as the aircraft and that's why you get sick in the simulator but not the aircraft, because there's some discrepancy in what the simulator's doing relative to the real thing. Then you say, well, maybe it's really bad for us to get them to adapt to the simulator because then they are adapting to something that isn't going to transfer. But maybe that isn't true. Maybe that isn't a problem to get them to adapt to the simulator. Maybe when they are adapted to this they are not getting the sickness. They are still learning things that really are useful. It's only if you demonstrate that there's a negative transfer between the simulator and the real plane do you have to worry about whether or not it's important that you control simulator sickness. And so do you know that?

DR. KENNEDY: We have said everything that you have said, and it is the paradox of this business. We know that realism makes for better simulations in one sense, but it may also make things more compelling, therefore it may make people more likely to get sick in another sense. All these things are connected.

DR. MCCAULEY: I would try answering his question: We don't know the effects of simulator sickness on training effectiveness. But we can surmise--what Bob says.

DR. DUNLAP: So, the simulator is obviously not doing a perfect job of simulating an airplane because, indeed, people are getting simulator sickness, which they don't get in a plane. Even so, if you can still show that they are learning a whole lot of things that are useful, then perhaps we should let them adapt to it. That takes away from the distraction factor. And if we cannot demonstrate a no negative transfer of this not-perfect simulation to the plane, then you've got everything you want. Right? You've got a person who isn't feeling nauseated while he's in the simulator and learning things that are useful. That would be in support of doing things that would get them to adapt. We may not have to change the simulator very much.

6.4 Accidents Based on Simulator Post-Effects and Possible Restrictions on Post-Simulator Flight

DR. MCCAULEY: I agree with that. The only thing I think we have to be concerned about is that during this period of adaptation in the simulator when he goes flying later that day or the next day that the probability of an accident is not increased.

DR. WELCH: That's because they haven't learned those two different worlds yet.

DR. MCCAULEY: Eventually I agree that he'll learn both of them.

DR. WELCH: That's a dangerous thing, while they are learning to discriminate they may have an accident.

DR. MCCAULEY: We think that that may be the case, we don't know.

DR. WELCH: Not just being in an airplane, also they can get them while driving a car.

DR. KENNEDY: One of the suggestions that was made was that perhaps early in training in the simulator, restrictions be place on people for a number of hours.

DR. WELCH: That certainly seems reasonable.

DR. KENNEDY: It may be able to be withdrawn later on.

DR. MCCAULEY: You don't really even want an 8-hour rule or 12-hour rule because it puts constraints on their operational flight schedules. You'd have to have everyone in the simulator early in the morning in order to get them in the airplane late, if you have even an 8-hour, or they'd have to come in in the middle of the night so they could fly during the day.

DR. BERBAUM: It would mean you always have to fly the simulator second in the day. In other words, fly in the morning outside and fly in the simulator in the afternoon.

DR. KENNEDY: The real problem is that flights are scheduled and then something comes up, either someone can't, or the engine doesn't work. And so a 12-hour rule totally removes flexibility.

DR. MCCAULEY: Two incidents reported in the literature frightened most people about this accident possibility. In one of the very first studies in Pensacola in about 1950 by Miller and Goodson, one of their subjects in a helicopter flight simulator had to stop his car, get out and walk around because he was so disoriented he was afraid he couldn't even drive his car home. What if this guy were flying the aircraft instead of driving his car. The other one was from the Air Force studies. And I still find it a little puzzling, but where Kellogg and Castore were talking about these guys who would lay in their bunk at night and all of a sudden the whole room would appear to go inverted.

DR. WELCH: In the dark?

DR. MCCAULEY: Watching TV. Again, can you imagine what if this guy were flying at this point.

DR. KENNEDY: There are two others. There is the helicopter pilot who couldn't set it down, was going to turn over the controls, flying a real helicopter. There is a suspicious F4 punch-out where someone claimed that he felt just like he felt when he was in the 2E6 the day before and punched out.

6.5 Long-Term Effects

DR. WELCH: I can get people back into the experimental situation who are immediately adapted, even though they haven't been there in a week or two, before they even are exposed to the prismatic displacement that I use, who show partial adaptation. But I'm sure they didn't go around missing doorknobs during the interim. The savings can be elicited with circumstances. I think you have to be put back in the same stimulus, which makes it crucial to see how much similarity there is in the peripheral aspects of the simulator and those of a cockpit. You've got a lot of other things that really aren't anything to do with the actual performance but which they probably put into simulators to make them look familiar.

DR. KENNEDY: I believe one of the things that could be done is to sit carefully with the duration of the stimuli that you use. That is the exposure duration, the magnitude of the effects, the amount of time between exposures, and then the post-effects and their duration and how long they last and how severe they are, and see if there is some lawful relationship that would cut across the many different environments to see whether time, itself, can tell us something.

I believe that if you have a one-day exposure, the posteffect spontaneous recovery, if you will, may be much more substantial than if you have a 15- or 20-minute exposure. I think that there is the possibility with highly-distributed exposure, long-duration exposure, I believe that there can be spontaneous onset, possibly in impoverished situations, that might be missed by one-hour exposures and two-hour exposures, and then no more again.

DR. WELCH: I think that readaptation is a good suggestion. But you can't just get them back to normal right there and assume that that's enough, because I think there will be spontaneous recovery of the sort that Pavlov made famous, where you think you've got it extinguished but then you put them back in the environment a week later and, bingo, it comes back again. You'll have to test it and see.

(WHEREUPON, the meeting was concluded)

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APPENDIX A

QUESTIONS POSED TO CONFERENCE PARTICIPANTS

1. The conflict theory implies that greater incidence of sickness will occur when there is greater conflict. What is your opinion of this statement?

2. Do you have an opinion as to how the magnitude of the conflict can be determined? Do you know a way to quantify the conflict? Does temporal rearrangement have the same disturbing nature as spatial, or is it qualitatively different?

3. It may be possible to reduce the symptoms experienced by individuals in flight simulators by adapting within the simulator or by pretraining on another device. Do you have an opinion as to whether adaptation or pretraining will be generally helpful? Are there hazards?

4. Of what importance do you believe head movements incidental to the movement of the simulator platform or visual scene are in the production of symptoms?

5. If you have an opinion, what flight maneuvers would you predict to be the most nauseogenic in a simulator? Would there be any difference depending on the experience level of the operator?.

6. How important do you believe suggestion is in promoting or countering symptoms?

7. It may be possible to adapt to two or more perceptual worlds simultaneously. Do you have an opinion as to whether this is a good way to solve the simulator sickness problem or not?

8. Of what influence do you consider the subject's physical state in the promotion of simulator sickness? If you were asked to list guidelines do you have an opinion as to how to caution operators prior to a simulator hop? What about being sleepy?... sick?... hungry?

9. When the aircraft exceeds certain design limits of the simulator software the simulation ends, sometimes with a freeze in an unusual attitude. If the scene fades-out during a "freeze" there seems to be a reduction in visual spatial disorganization when compared to no fade-out. However, no equivalent fading-out of the inertial stimulus is available. If you have an opinion, would you comment on whether "bumps" and "jerks" might be a useful analogue. For example, not necessarily concordant vestibular inputs could signal to the individual that he has bumped to a stop after being in a descending banking turn. Would this help? Are there other potentially discordant stimuli (proprioceptive, auditory) for which similar "fade-outs" would be useful?

10. Should persons who are grounded for ear block, sinus, etc., be permitted to fly a simulator?

11. After flying in some simulators pilots are not permitted to fly in an aircraft for 12 or 24 hours. Does this seem reasonable? Do you believe that a rule should be enforced whether or not a person has symptoms? What about driving a car? Do you have an opinion of a 12-hour delay before first flight and two hours for the second flight?

12. Some simulators appear to have an asynchrony between the visual and the inertial display. For example, the central computer, the platform, and the visual scene must all be integrated, but there are constraints such that the visual requires somewhat more computation time than an inertial. Therefore, in those places where it has been studied, the visual and inertial signal may not begin at the same time, nor end at the same time, nor move to the same place at the same rate. Moreover, when wash-out is added, the problem could be compounded. Do you have an opinion about lags? Do you think that phase relationships can be as strong a conflict as displacement and distortion? Does temporal rearrangement involve as much conflict as spatial?

13. Would asynchrony/distortion of visually displayed information be more or less nauseogenic than between visual and inertial?

14. The equations used to generate the dynamics of simulators often employ numbers based on small samples of individuals. How well do you believe these average values characterize the inertial environment for pilots? Do you believe that this could be a source of conflict in some persons? Is it too extreme to consider individually tailored motion cueing?

15. A study some time ago showed that there was no appreciable improvement in transfer of training when concordant motion cueing was provided over a condition where the motion cueing was random. In that study it was also described that no subject remarked on the incompatibility of the motion condition. This occurred in a flight trainer without a wide-angle visual input, but suggests that whereas some motion may be useful for realism, it may not be necessary to have it veridical. Do you have an opinion as to whether faithful representations of motion are important for simulator sickness? Is it possible that totally incompatible motion could reduce the sickness? Would your answer be different depending on the experience level of the individual?

16. How important do you believe the very low frequencies of inertial motion are from the standpoint of nauseogenic properites? Is this an instance of resonance? Is there a conflict here? What would you predict is the frequency in a simulator? Do horizontal oscillations ($gx + gy$) have similar problems?

17. Do you have an opinion as to whether biofeedback, support therapy, set, leadership, motivation, suggestibility would be useful constructs to discuss to reduce symptoms? Which of these do you see as being the most useful? Would there be strong interactions as a function of individual make-up? How likely is it that pilots would avail themselves of these approaches?

18. Some simulators show size constancy information through familiar objects and others have mostly geometric representations. Is it possible that this could contribute to conflict situations? Is it possible that contrast (high or low) could influence these issues?

19. Pilots often seem to sit forward of the design eye. If so, they could induce distortion by being off-axis for some of the displays. Do you think this could be a factor in simulator sickness? Do you have an opinion about a way to define a metric of distortion which would provide a limit that should not be extended?

20. Do you have an opinion about what distortions may not be nauseogenic (e.g., color, luminance) and which may (depth cues, movement)?

21. Sometimes straight lines do not coincide across different visual displays. Although annoying, some do not consider this to be nauseogenic because motion need not necessarily be involved. Do you have an opinion as to whether distorted geometry contributes to simulator sickness?

22. What do you think is the mechanism whereby dynamic distortions contribute to simulator sickness?

23. Some have remarked that an overly sensitive stick can potentiate simulator sickness. Do you have an opinion as to how this can occur? Does the pilot impart more motion? More at .2Hz? Get inappropriate gain in feedback based on past experience?

24. Would a narrowing of the field of view minimize sickness? If not a general rule, under what conditions do you believe that the field of view would potentiate the problem?

25. If two particularly sharp and clear stimuli (a visual and inertial input) were out of phase (or spatially rearranged) would they be less nauseogenic if the visual were blurred or out of focus? Is there an equivalent way to "blur" or defocus an inertial stimulus? Would that work?

26. It is generally agreed that vision is the dominant sense, but when motion is involved it may be less so. Can you describe the conditions where it is likely to occur? Would adaptation be more likely to occur in conditions where vision correctly is interpreting reality or the converse? On what basis could vision adapt more quickly?

27. It may be possible to create a mismatch between two visual stimuli and not directly stimulate the vestibular system. For example, linear perspective, interposition, and size constancy all provide cues to depth and could be placed in opposition or conflict. Do you have an opinion as to whether motion sickness could result with any disparate combination of these?

28. Do you have an opinion as to how readaptation to post-conditions can be best effected? Do you believe any hazard exists subsequent to exposure? If simulator exposures were for 3-4 hours would this make a difference?

29. What do you think is the source of eye strain that many pilots report? Do CIG systems create some of the same visual problems of VDTs? How about headache or "fullness of the head"?

30. What is your model of the motion sickness problem?

31. One way to reduce the perceived magnitude of the conflict is with experience. Some have argued that the regularity of the conflicting inputs would permit easier adaptation. How important do you believe it is to have consistent distortions versus the converse from the standpoint of their nauseogenic properties and the ease with which one may adapt?

32. How long should a simulator hop be? Are post effects likely to be monotonic with per effects? What do we know about the shape of the learning/ adaptation time-course function?

33. What kinds of problems do you believe would be created by different roll ratios in different CIG displays?

34. It has been shown that adaptation to prismatic displacement which entails latencies of > 300 msec is protracted and may not occur at all. What relevance might this finding have for cue asynchrony?

END
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