An example of this type of activity is the translation of data on machine-controlled adaptive training studies into specifications for the adaptive training features of the Synthetic Flight Training System (SFTS). In addition, NTDC has for a number of years been supporting research on team training with particular emphasis on decision making in tactical situations such as anti-air warfare and anti-submarine warfare. A point has now been reached where findings should be evaluated in terms of what needs to be done in order to incorporate them into training systems.

We don't want to see technical reports filed gathering dust on a shelf. A research report, either from our laboratory or from a contractor, should be the beginning rather than the end of an endeavor. We want to implement the findings of our research studies into training device design and use. But, this translation process is the hardest part of the entire research process. An all out effort is being made to do this, but the point is that much thought and effort is required. However, we have committed ourselves to this type of effort on all our projects.

The reason the translation process is so difficult is that there is no training ground for the development of research translators. Who should be trained for this function and how to train for it are areas requiring investigation. We would be interested in your ideas on this subject. In fact, we welcome your views on any aspect of our program.

THE USE OF THE EFFECTIVE TIME CONSTANT IN TRAINER DESIGN

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Before discussing the effective time constant of a man-machine system and what possible use it could be in the design of trainers, I want to give you some background and some explanation of why there should be any need for such a concept at all.

In 1950, I was involved along with the late Alex Williams as an investigator in a project which set out to determine the answer (or at least a partial answer) to the question: What is the relationship between transfer of training, and the fidelity with which the equations of motion are represented in a simulator? After a year of study we learned something about the mathematical models used to describe the motions of aircraft and how these math models become physical models in simulators to represent or simulate the dynamic response characteristics of the aircraft. We learned also that there could be different math models for a given a/c, or at least different variations of a model for a given aircraft, when that model was actually reduced to hardware in a simulator. We concluded that if we were to conduct transfer of training experiments to test the effects on transfer of training of even the major portion of the possible variations of the way the model could be implemented in a simulator we would, without doubt, be carrying out experiments into the 21st century.

We learned, or were told at that time, that the problem of the relationship between amount of transfer of training and fidelity of simulation was really not a problem at all since it cost very little more to implement the equations to make a really high fidelity trainer than to make one of lesser fidelity. In the face of this declaration and in the face of the number of experiments to be run if we chose as our independent variables in transfer experiments variation of the math model, we terminated the project. In doing so we tacitly acquiesced to the training philosophy that the best training simulator is that one which most faithfully represents the aircraft being simulated. We also abdicated our responsibility for evaluating a trainer in terms of its training value in favor of evaluating it on the basis of its "flying like" the aircraft.

We went underground but not happily. It will never be satisfying to me to see a trainer evaluated by having an expert judge it as to whether it "flys like" the aircraft it was designed to simulate. All of you in the simulator business know what you go through in catching up with and meeting that elusive criteria.

Now you will say, that in reviving the fidelity of simulation controversy, we are beating a dead horse, since it is self-evident that the simulators we build under the high fidelity training philosophy do train and train well. Yes, this is true. We don't know how well or whether we could do better for the dollars we spend. There are more important reasons why we should not follow this philosophy which I shall come to shortly. But how many of you are really happy with the present hi-fi philosophy. I have seen the simulator customer sweating and puzzling over writing specifications or evaluating proposals wondering and guessing what one thing or another will do to transfer of training. I have also seen, the simulator designer sweating and puzzling over whether to leave this or that in or take it out. In the end, the criterion becomes more what the customer likes or will judge to be good fidelity rather than any definitive evidence as to what will get the most training value for the dollar.

With our present day digital computer capability the high fidelity philosophy with respect to the descriptive equations becomes even harder to uproot. This philosophy is now being extended into other areas of simulation in which our problems are likely to be compounded. We are now in the midst of the same transfer of training questions with respect to motion platforms, visual displays, the auditory spectrum - and who knows but what smell will be next.

When we get into these other areas of simulation, the basic questions stand out more clearly. In the area of motion, vision and audition it can be clearly seen that we do not need in the simulator those physical aspects of the operating environment which are outside man's capabilities for sensing them. In fact, in the area of motion, hi-fidelity simulation becomes quite impractical. Also, I think we wouldn't reproduce in the simulator the ultra violet or infra red portion of the spectrum. Or, in the case of the simulation of auditory cues, we won't go into the range of 30 or 40 thousand cycles. On the other hand, I might say - why not? We've been doing the analogous thing for years in the case of reproducing the equations of motion and it probably wouldn't add much more to the cost of the trainer.

The hi-fi training philosophy is so patently unsuitable to the solution of the motion problem that we are now expending some research effort seeking to determine the relevant or necessary and sufficient motion cues.

My objective up to this point is really to bring us back to the trainee as the focal point in designing training simulators and away from that of physical realism. We need more attention paid to really being definite and detailed about what it is we wish the trainee to be able to do when he finishes his training in a simulator. To do this we need to turn our attention to what physical aspects of his environment and his vehicle, can he (and does he) sense and use in doing the job for which he is being trained. We need one more thing. We need these physical properties spelled out and quantified in a way that they can be used by human factors personnel in evaluating trainers and doing transfer of training research. At the same time they must be in terms which can be used by the simulator design engineer in building simulators.

We need to turn to the question of what do we need for training rather than what do we need to do to simulate the real world. I think we need to clearly understand that what we need in a simulator are those physical properties which are discernible by man and therefore form a stimulus complex for him. We need to know what changes in these physical variables can be discriminated and how discriminable changes in them are related to operator control behavior. That is, first, we need to describe the important useful physical properties of the real world setting. Next we need to determine what aspects of these properties are necessary and sufficient for incorporation into simulators for training.

Obviously, this is a difficult problem or we wouldn't be facing it yet today. It is obvious also that we cannot declare a moratorium on building simulators until we get the answers. We do need, however, to get much busier on the problem for some rather important reasons.

First, with the addition to the simulator of motion, external visual attachments and auditory cues the proper time and magnitude relationships of these cues, one to the other, become important. With all of these channels of information now opened for the man in the simulator we may need to ge back and look again at those things we left out or approximated in the describing equations of the aircraft. Some things not detectable by the pilot when his information came from the cockpit instruments may now be glaringly apparent through the relatively highly magnified external visual display or from the motion cues.

Improper time or magnitude relationships among information sources cause a conflict of cues or cuase their perception in the wrong time relationship.

The diagram in Figure 80 may serve to make the point clear.

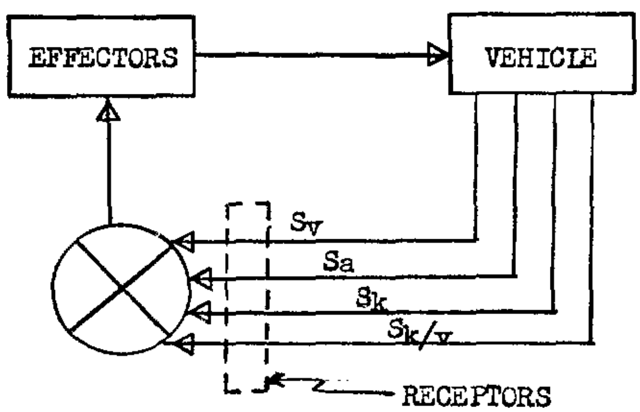

Figure 80. Summation of visual (S_v), auditory (S_a), kinesthetic (S_k), or kinesthetic/vestibular ($S_{k/v}$) stimuli before an effector output.

The figure represents the several stimuli from the vehicle to the operator as passing through a summing junction to emphasize the fact that the operator's output is a complex summing of the total complex of stimuli he receives. He receives visual stimuli (S_v), auditory stimuli (S_a), kinesthetic stimuli from control movements (S_k) and a complex of kinesthetic/vestibular stimuli (S_{kv}) from body motion. There must be a consonance of these stimuli at the summing junction if we are not to have conflict of cues and improper time and magnitude relationships among them.

Second, we must describe the important useful environment of the operator, what cues he uses, and how each is related to his learning process so that we can make better use of training technology. The hi-fi simulation philosophy does not lend itself to this. It is too global through presenting everything that is engineeringly feasible. It says in effect, let's give the trainee every cue possible but it does not identify the information sources, how their variation is perceived, which are difficult to master and which are less so, what is the relative importance of visual, motion or auditory cues in the various segments of the task or how they are combined and used by the trainee. Not knowing these we cannot apply, or even investigate, the application of training technology such as direction of emphasis or make full use of such advanced training concepts as adaptive training. If we did know these in detail we could seriously consider the environment in which the trainee learns as a training system rather than thinking just of a training simulator. In such a training system other training devices and methods might be used to supplement or complement the complex simulator.

Third, in some cases the hi-fi training philosophy is simply impractical. The best example is the case of simulator motion. In this area of simulation we have been forced to give consideration to the human perception side of the problem. We cannot, as we have done with simulation of the equations of motion, simply say we will go all out to make the simulator as physically comparable to the aircraft as engineeringly possible. If we follow the hi-fi logic with aircraft simulators we end up with a flying simulator.

In motion we have an accentuation of the problem we have with other aspects of simulation. The basic problem of implementation of the aerodynamic equations, simulator motion, external visual displays and auditory cues is not one of physical representation of the real world. Rather, it is the psycho-physical problem of the relationship between the physical world on the one hand and how it is perceived on the other.

In configuring a simulator we are interested in identifying and describing how the human operator perceives those physical parameters which are related to control of the vehicle. Further, we are interested in configuring the simulator (or the training system) such that he learns in the most efficient way to use these variables to exercise control. This means that we have the dual problem of (1) identifying the parameters used by the man in control and (2) relating the physical expression of these parameters to operator perceptual and control behavior. We find that some parameters which we could measure and implement in a simulator simply are not perceptible by the human operator. There are measurable properties of the motion of an aircraft which man cannot perceive. Also, there are properties which can be perceived through one sense modality which cannot be sensed by another. The problem of what motion cues the operator discriminates and uses and how these cues are meshed with the visual cues epitomizes the whole simulation problem.

The time has come to stop and think hard about our priorities in the solution of simulation problems. We need to delineate the specific areas in which we need information about how man discriminates and controls. It would help us to be able to generate some sort of model as to how man uses and relates his several sources of information in exercising control.

The concept of an effective time constant is an attempt to generate a portion of such a model. Although tentative and not tested with any degree of completeness it does offer an interesting start. It deals with man's continuous control behavior in the type of error nulling task required of him by the vast majority of machines.

The effective time constant (t_e) grew out of work aimed at making recommendations for the configurations of helicopter simulators. This work was sponsored by the Human Resources

Research Office (HumRRO) through its aviation research unit (Division No. 6). The initial question to which we addressed ourselves was the rather broad one of "What makes helicopter control difficult?" - both in terms of what contributes to lack of precision of control and what aspects take the relatively longer time to learn. The response dynamics of the helicopter being what they are, we looked into how these dynamics might be described in a way which could be related to operator control behavior. We did not wish to consider each of the innumerable ways in which the equations could be varied or approximated in the simulator. We felt that the operator is not sensitive to, i.e., cannot perceive, all the subtle changes that can be made in these equations.

It is a property of machines that their response to a given control input is perceptible as an output by the human operator after some finite period of time. We took as a premise that the response of the machines, as an output, must achieve a certain value before it can be discriminated as an output by the human operator. As the operator's perceptual threshold raises, the output of the system will need to reach a higher value before it is perceived, thus lengthening the time between control input and perceived output. As the operators threshold is lowered the time is shortened.

It would seem a reasonable premise also that the human operator should be able to exercise more precise control when he is able to detect an error while it was still small rather than after it becomes large - in a manner similar to an automatic error nulling device. We would hypothesize that the sooner the human operator gets feedback as to the results of his control input the faster he will be able to learn and, after learning, more precisely control the machine.

It appeared, then, that there were quantifiable properties of the machine which could be identified as determining the machine's speed of response which, coupled with man's perception threshold, could be formed into a construct which would be predictive of man's control behavior. This construct we termed the effective time constant of the man-machine system (t_e) and it simply measures the rapidity with which the operator receives feedback as a result of his control input.

For first order systems the effective time constant of the man-machine system is an explicit function of the gain of the system (K), time constant (τ) and the operator's threshold (T). In second order systems it becomes a function of gain (K) natural frequency (ω), damping ratio (δ), and operator threshold (T).

The vehicle response time may be determined from any of those coefficients or machine response descriptors which are prime determiner's of its speed of response. The operator's threshold may vary due to physiological or psychological stresses, training in detecting and discriminating the vehicle output, work load and the like. Any training or any vehicle design which serves to lower the operator's threshold for perception of vehicle output can be hypothesized to increase the operators precision of control. Conversely, any condition which raises that threshold would decrease control precision.

It should be clearly understood that the perceptual threshold of which we speak is not just the visual threshold alone. It is the threshold of each and every sense which is stimulated by the vehicle output. Thus, if the output of the vehicle can be sensed by both the visual and the kinesthetic/vestibular senses, that output may rise above the threshold for one sense before it does another and serves as the basis for control behavior.

This construct may be used to explain experimental findings such as those in which it was found that greater precision of control may be exercised in a helicopter simulator with a moving platform than can be exercised in a fixed base simulator. (Feddersen, 1962)

The complex relationship holding between visual threshold, kinesthetic/vestibular threshold and the speed of response of the vehicle must be taken into account in putting together simulators which incorporate motion platform and visual attachments. The effective time constant construct offers some insights into these human threshold-machine dynamics relationships.

Under the sponsorship of the Human Factors Laboratory of the Navy Special Device Center the hypothesis that the effective time constant was related to precision of control was tested. The hypothesis tested was that precision of control in a second order system was a function of the effective time constant of the man-machine system and was independent of the values of the natural frequency, damping ratio and gain going to make up the t_e. The findings were that precision of control was related to the value of the effective time constant. Further, a given t_e could be obtained by different combinations of gain, natural frequency and damping. The effective time constant was predictive of performance while the vehicle gain, frequency and damping were not. These findings are reported in Naval Training Device Center Technical Report 67-C-0034-3 (Matheny and Norman, 1968). We have not yet had the opportunity of testing experimentally the effect of variations of threshold (T) - a necessary test of the construct.

These findings were interesting in several respects. First, they showed that man-machine systems could be described in terms which are both man and machine related and predictive of man's control behavior.

Second, they showed that simplifying constructs can be evolved which describe systems in terms of their perceptual equivalence, or more precisely their operational behavior equivalence and that these constructs, while based on properties of the machine, are the overriding determiners of performance and not the machine properties in and of themselves.

Third, they open the door to configuring trainers in terms of such constructs and give the trainer design engineer much more latitude in design.

Fourth, they show that constructs based upon properties of both the man and the machine can be derived which can serve as the independent variables in determining how their variation in trainers is related to transfer of training.

Fifth, they open the door to the use of such constructs in guiding the training of the student through emphasis or direction upon different aspects of the learning task as he proceeds through his training and to their use as adaptive variables in adaptive or self adjusting training devices.

The effective time constant, as a construct, is, I believe, a start toward a model of human control behavior from which we will be able to predict whether a given vehicle will be difficult or easy to control and from which we can build training devices whose training value we can reliably predict. After all, the vehicles of today are the product of an evolutionary process during which only those were retained which man was able to control.

A common denominator exists in all of them - i.e., man can control them. Those which he can't control we seek, in one way or another, to make like those which he can. There must be a common thread running throughout these vehicles which, coupled with man's perceptual and control abilities, we can identify and describe for the understanding and prediction of control behavior.

Therefore, my hope is that we will concentrate more on reaching an understanding of man's control behavior and a capability for predicting it from study of the machines he controls. When we have formulated a cohesive model based upon properties of both the man and the machine from which we can predict man's control behavior we will have the capability for determining the relationships between the properties of the model and transfer of training.

These relationships will be general ones, resting on common properties of man and machine which we can then use in specifying and designing our training simulators. I think this a more useful as well as a necessary alternative to the hi-fi design approach. The t_e construct is a small but promising beginning.

I would like to end on a note by the former Secretary of Health, Education and Welfare, John Gardner, in his book "No Easy Victories."

"A...subtle exit from the grimy problems of the day is to immerse yourself so deeply in a specialized professional field that the larger community virtually ceases to exist. This is a particularly good way out because the rewards of professional specialization are very great today, so you may become rich and famous while you are ignoring the nation's problems." This is a point to which we may well give some thought in our own smaller world of simulators and trainers.

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A GENERAL PURPOSE SIMULATION SYSTEM

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The General Purpose Simulation System is an International Business Machines Application Program based upon statistical techniques, primarily queuing and probability theory. The program is written in a language similar to Fortran, The General Purpose Simulation System Processor.

The General Purpose Simulation System has been structured by Conductron-Missouri to provide a means of examining the loads placed upon an instructor in any specific training system and to make a determination of student to instructor ratios based upon the demands placed upon the instructor by the specific training system.

The program will manipulate input parameters, simulate all interactions between students and instructors, and tabulate and print out all transactions and their associated elapsed times. Any transactions between student and instructor which were delayed because of other student-instructor transactions will be listed with their associated delay time.