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THE FUTURE OF SELECTIVE FIDELITY IN TRAINING DEVICES

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NOTICES

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This report has been reviewed and is approved for publication.

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Since the inception of modern simulation, the designers and users of training devices have attempted to replicate as many physical and functional stimuli as possible in the training device. There are three primary impediments to this activity: our frequent inability to specify the kinds of stimuli that are required, our technological difficulty in replicating some stimuli, and the cost of replicating stimuli. The constraints cited above have led the training device community to develop the concept of "selective fidelity," meaning that we have to be very selective about the stimuli that we choose to replicate. This report presents arguments that our definitions of selective fidelity now need to be altered to fit recent behavioral and engineering developments. Over the years, we have improved our ability through research and analysis to define the important stimuli. Also, our engineering capability to replicate formerly difficult stimuli has improved significantly. Finally, there have been dramatic decreases in the cost of providing high fidelity simulation. In this report, we discuss our belief that while the concept of selective fidelity will remain important to the training device community, the definition of selective fidelity will be more focused on trainee learning requirements than on analytical and technological shortcomings

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THE FUTURE OF SELECTIVE FIDELITY IN TRAINING DEVICES

INTRODUCTION

Since the days of the early Link trainers, the simulation community has striven to re-create for trainees a virtual world that is as close to the real world as possible. To do this, training device designers have attempted to replicate the stimuli and response modes that trainees would eventually see and use in the real world. Despite these efforts, training devices always have fallen short of replicating a complete set of the outside world stimuli.

A variety of problems have plagued these efforts. Designers and instructors have frequently had great difficulty in defining precisely the characteristics of the stimuli to be presented to the trainees. When training requirement experts have been able to adequately define the stimuli necessary for a task, the designers have frequently been unable to replicate the stimuli because they lacked the technology. Sometimes, the technology has existed, but the procurement and/or sustainment costs have been too high.

Selective Fidelity

The end result of the problems cited above has been an approach referred to as "selective fidelity." That is, since we can't simulate all of the stimuli that are present in a real-world task or function, we must then choose to simulate only those stimuli that truly are necessary to perform the task. We <u>select</u> the <u>fidelity</u> level that we will present to the trainee. While this approach has proven beneficial, especially in developing tactical training devices, the problems cited earlier can greatly hamper this approach.

There are two main types of fidelity: physical and functional. (Other types of fidelity are sometimes discussed, such as task, behavioral, psychological, equipment. However, for purposes of this report, we will focus on the two types most commonly discussed: Physical and Functional.) For a complete discussion about fidelity types, we recommend Fink and Shriver (1978). Physical fidelity refers to the physical layout of the operator's simulated environment. Are the knobs, dials, displays, controls and so forth present and in the correct positions? Are the visual stimuli present in the kind and degree that we would expect to see in the real world? In other words, does the synthetic environment "look right?"

Functional fidelity refers to the way the simulation acts and its similarity to the real world. For example, does the simulator respond to the operator's control inputs in the way the actual equipment would? Are the aerodynamic or hydrodynamic equations accurate? In other words, does the simulation "act and feel right?" Functional fidelity is very much focused on the stimulus presented to the operator and the response that the operator makes.

For every simulation task, we have an array of fidelity levels to choose from, but we typically are not able to reach the real-world level of fidelity. Our inability to precisely define stimuli and technology/cost limitations conspire against us. We must then select the fidelity level that will allow us to meet our simulation requirement while still conforming to our technology and budget constraints.

This selection process requires a number of trade-offs between the training requirement, the technology available, and budget. The fact is, we seldom are able to select the fidelity level that we truly desire. We usually must settle for the level that will allow the training mission to be accomplished affordably.

In training operators in psychomotor tasks, we generally feel that the quality of the training will increase with each incremental increase in physical and functional training fidelity. In operator training., we strive to "select" a fidelity level that will replicate as many of the physical requirements and functional fidelity as possible, including trainee response modes. Research and experience have shown that relatively lower levels of fidelity are required for familiarization and cognitive training. Tactical training is an example of cognitive training.

Examples of Selective Fidelity

Selective fidelity has proven most popular as a concept in the development of tactical training devices such as the Advanced Research Projects Agency's (ARPA) simulator network (SIMNET) (Alluisi, 1991). The goal in SIMNET was to develop a networked set of simulators that would allow tactical commanders at the battalion level and below to learn how to tactically deploy and fight their armored units. Only those displays and controls deemed absolutely necessary for tactical training were provided to the tank commander, gunner, and driver.

Cost was a major factor in deciding not to replicate all of the controls/displays and functions from the real-world armor. Since tactical training of the maneuver element was the objective, SIMNET designers decided it was better to spend money on many SIMNET devices with lower physical and functional fidelity than it was to spend money on fewer devices with higher fidelity. Since each physical feature and function that is replicated costs additional money, the only way to provide enough devices to satisfy the objective was to select only those features and functions that were necessary for the tactical tasks.

The result was the development of dozens of SIMNET devices that allow an entire battalion to train together. If the selective fidelity approach had not been used, and higher levels of fidelity had been selected, the Army and ARPA would have only been able to provide a relatively few devices. The result would not have provided the trainees enough manned armored units to achieve the objective. At the time of SIMNET development, the designers referred to their approach as the "60% solution." Meaning that only about 60% of the physical fidelity was provided to the trainees that they would find in their actual armored systems. Experience has shown that for tactical armored system training, approximately 60% of the physical fidelity seems to be adequate. Functional fidelity was higher than 60% for SIMNET, but still something less than 100%.

The Army provides much higher fidelity trainers for training gunnery skills to gunners and tank commanders in the Conduct of Fire Trainers (COFT). The COFT devices cost considerably more per unit than do the SIMNET devices, but they provide a higher number of the physical and functional stimuli a gunner and commander would expect to see in the real world. In addition, there are many more input controls than are provided in the SIMNET devices. This level of fidelity is required for training gunners to hit their targets and for training commanders and gunners to coordinate. It is assumed that basic gunnery coordination skills are already possessed by commanders and gunners when they start to learn broader tactical skills in SIMNET. If SIMNET focused on the 60% physical fidelity solution., then it may be fair to say that COFT focused on the 80%+ physical and functional fidelity solution for gunnery tasks. The physical and functional stimuli for gunnery training provided in COFT may not exactly match the real world stimuli, but they come fairly close. The functional fidelity needed for tactical armored maneuver element tasks was much lower in COFT than in SIMNET because tactical maneuver element tasks were not intended to be trained on COFT.

It should be pointed out that even in COFT, a selective fidelity approach was used. Detailed training device front-end analysis showed that not all of the real world stimuli were required to teach the gunner and commander their tasks. Therefore, there was no attempt to include those stimuli. In addition, there were some stimuli that were deemed important, (e.g., the ability for the commander to look outside the open hatch) but they were not replicated for one of three reasons: (a) they cost too much to simulate, (b) it was not technologically feasible to simulate them, and (3) it was impossible to define all the possible stimuli due to limitations in our behavioral analytical techniques. Such occurrences happen in <u>every</u> training device development.

For some time now, the success of the 60% solution SIMNET approach has been touted as the optimal way to proceed for all simulated tactical training tasks. The argument has been that we simply either can't afford to reach for much higher levels of fidelity in tactical training because it is too expensive, or it is not necessary. This argument says that we can achieve quality tactical training by making use of the selective fidelity approach. As the Department of Defense (DOD) moves more and more into using networked trainers for service unique and mullet-service training, there is continual interest in replicating only those stimuli and control inputs that are deemed absolutely essential for tactical training.

There should be some concern with absolute acceptance of the 60% solution approach as the optimal method for achieving tactical training in networked environments. We have found in tactical aircraft training that a considerably higher level of fidelity is required than 60% for some pilot training functions. Single-seat fighter pilots must perform: the command function that a tank commander has to perform, the vehicle control function that the tank driver has to perform, and the weapons deployment function that the tank gunner has to perform. While the command function may be able to use the 60% physical fidelity level, we have discovered that the weapons control and deployment functions need higher physical and functional fidelity levels.

Aircrews developed their own response to achieving desired fidelity. Frustrated by the laborious and lengthy process of analysis and media selection, the user simply stated, "make it look and act like the weapon system." The solution, although expensive, was to literally "cut off the front third of an aircraft" and stimulate it. However, while high fidelity cockpits were achievable in this way, the complementary synthetic environment that would permit a full range of training was not so easily achieved. Simulators supporting single-ship missions evolved to accommodate a full spectrum of training from individual task to crew mission training. Simulators supporting fighter missions also evolved to achieve full cockpit fidelity, but typically were designed to support individual, procedural training at the task level. While excursions were made using full motion and visuals, fidelity limits did not permit credible multiship mission training. In both applications, families of trainers were used to augment training at reduced fidelity levels and cost.

However, it was the fuel crises of the 1970s that precipitated the push for simulation to actually replace flying hours that created the real dilemma. How much fidelity was enough? How many simulator hours were required to replace an hour of flight time? While these questions have yet to be conclusively answered analytically, they are being overcome by events. Mission training requirements are escalating while flying hour erosion continues. Classic peacetime constraints such as funding, safety, and security are now complicated by environmental constraints and training area encroachment. The results are an expanded use of simulation and acceptance by many aircrews of simulation as a potential solution. However, this should not be construed to mean that simulation fidelity is now adequate or that selective fidelity is the total answer.

The same factors that forced designers to make selective fidelity decisions (cost, technological problems, and difficulty in defining all possible stimuli) still plague fighter simulator designers. Selective fidelity is still required, but the ultimate level of fidelity will vary depending upon the domain of training.

FUTURE OF SELECTIVE FIDELITY

We believe that the concept of selective fidelity will always be a major concern of the training device community. However, we also believe that our understanding and use of selective fidelity will need to change as a result of a number of current trends. Following is a discussion of three trends.

Behavioral and Cognitive Research Contributions

For many years, the primary method of defining which stimuli to simulate was primarily an analytical one. That is, analysts would observe experts and journeymen performing their jobs and attempt to determine which stimuli in the environment were prompting certain types of responses. In addition, the analysts would talk with those same experts and journeymen to get their opinions of what was required to perform the task. There was some basic research about human performance that helped, but the analytical technique was still the prime method (Miller et al., 1977).

This reliance on primarily analytical data rather than experimental data has been a major reason for adapting a selective fidelity approach to training device design. In many cases, the training analysts and psychologists were simply not able to specify a complete set of stimuli for successful task performance because they didn't have the tools. This difficulty has been a major impetus for using a selective fidelity approach. In fact, in many cases, it has proven difficult even to specify all of those stimuli which are crucial.

The empirical research that was performed concerning vital stimuli was directed at overt stimuli and response characteristics of the tasks. Researchers would provide various sets of simulated cues and then attempt to measure trainee responses to see how closely they matched responses from the real world. If the responses in the experimental conditions corresponded relatively well to the responses in the real world, it was assumed that the simulated stimuli were then also faithful representations. What made the experimental stimulus a faithful representation was not often discovered. A major reason for this lack of discovery was that the psychological techniques, theories, and measures necessary to make those discoveries did not exist or were not adequate.

In recent years, there has been new thinking about how humans learn and perform. Cognitive approaches to examining learning and training requirements have begun to be common in the training analysis business. These cognitive approaches, such as the Integrated Task Analysis Methodology (Beckshi, Lierman, Redding & Ryder, 1993) and others (Bliss, Monk, & Ogborn, 1983; Cooke & McDonald, 1987, and Johnson & Johnson, 1987, as examples), allow analysts to look at more than just the external stimulus and response conditions of a real-world task. In addition, they can provide an insight into the actual thinking processes that an expert or journeyman use in performing their real-world tasks. Anyone who has performed training system analysis with experts and journeymen realizes the difficulty often inherent in "extracting" verbal descriptions of the stimuli that are required for successful task performance. Traditional Stimulus-Response (S-R) type analyses are only partially helpful in this articulation process. New cognitive techniques build upon existing analytical techniques to provide a better "window" into the expert's and journeyman's discrimination and generalization of stimuli.

Cognitive techniques also provide a better understanding of the cue recognition/selection process. Stimuli to the five senses surround us every moment that we are alive. We have a marvelous capacity to filter out from our conscious attention the vast majority of these stimuli. Our information processing system performs this filtering by analyzing each stimulus and comparing it to a huge store of memories from our long-term memory. A pattern recognition process then allows us to make a decision about whether a stimulus has meaning for us. In other words, is the stimulus to be treated as a cue for the expert or journeyman to make some type of response?

By better understanding the cue recognition/selection process, training analysts can now more easily define the complete set of stimuli that must be replicated in the training device. In the past, analysts had to make use of selective fidelity because the classical S-R theories and tools necessarily limited a definition of the complete set. Selective fidelity was almost forced upon the training device definition process because of the difficulty of defining anything more. Cognitive analysis shows great promise for defining the relevant stimuli for various tasks. This will improve our ability to specify physical and functional fidelity levels.

Improved Technological Expertise

The early Link flight trainers represented only a very few of the real-world stimuli that were available to a pilot while flying the aircraft. That was largely because the engineers of the time simply did not have the technology available to replicate many of the stimuli. Through the years we have greatly added to the repertoire of stimuli which can be simulated. Some examples are:

- Digital audio systems now allow a fairly accurate representation of the weapon system, communication and battle sounds that a warrior can expect to hear in the real world.

- Visual systems (image generators, displays, databases) have greatly increased the training designers capability to present realistic visual stimuli.

- Control loading technology has enabled trainees to experience realistic tactile and proprioceptive feedback.

- Considerable progress has been made in developing motion systems that fairly represent motion cueing. (However, motion system simulation is a good example of relevant cues and technology limits for tactical aircraft training. Research and experience failed to show the effectiveness of motion systems for training tactical fixed-wing aircraft tasks. Analysis showed limited ability to replicate the range of motion and sustained motion. Selective fidelity with force cueing, such as G-suits and G-seats, were just as effective for on-set motion cues.)

Despite the technological progress that has been made, the training device community realizes that there is still a considerable distance to cover before we can say that we are approaching 100% fidelity in the areas described above. We believe that the next ten years will herald a rate of engineering breakthroughs that will easily match or exceed the rate of improvements seen since the Link days. A very high degree of replication of real-world stimuli will be the rule and not the exception, as is the case today. Image generators, visual displays, databases, networking, motion bases, control loaders, and a variety of other simulation tools will all make dramatic advances. These technological tools and methods will allow training device designers to worry more about identifying a complete array of stimuli necessary for successful training objective accomplishment, and less about which stimuli are absolutely essential.

Microprocessor Cost Reductions

Costs of producing higher levels of fidelity have declined dramatically in the last decade. These price declines are due to the advances in microprocessor technology that have affected large sectors of society. The cost to produce various simulated stimuli (visual, aural, and proprioceptive) is obviously driven by the amount of computing power required.

Perhaps the best way to illustrate the effect of computer cost reductions on selective fidelity is by using an example from the tactical training domain. Compared to the visual imagery available at the time SIMNET was developed, the SIMNET imagery had a fairly impoverished visual scene content and resolution. The design logic was that for tactical training it was not necessary to replicate large numbers of visual stimuli or provide detailed resolution. It was enough for the tactical decision maker to know that a friend or foe was in a certain place. It was not of vital importance that high resolution be provided in order for tactical training objectives to be met.

In the future, however, image generators (IGs) that can provide extremely high levels of visual fidelity will be available at affordable prices effectively reducing dependence on selective fidelity. The price of a channel of simulated, high fidelity imagery has been dropping by about 75% every five years over the last ten years. We would expect that cost reduction trend to continue and, in fact, accelerate over the next ten years. Each tactical training device will have present the same degree of resolution to tactical trainees that has heretofore been available only to operator trainees (e.g., the tank gunners in a Conduct of Fire Trainer). The selective fidelity decisions that are made will not be driven by cost, but rather by factors more related to the actual training objectives, such as the phase of training and our ability to define real-world stimuli.

One result of this greater availability of high resolution visual imagery will be the demise of separate trainers for operator vs. tactical training. One simulator will be able to accomplish both of these goals. Tremendous cost savings will accrue from being able to train both sets of skills in the same "box." Large savings will be based upon reduced unit production costs because more of the same boxes will exist. Where before the SIMNET designers had to pick only those stimuli to simulate which were absolutely crucial to the tactical training task, now designers will be able to select from a much broader range of potential stimuli because the cost of simulation will be far less.

CONCLUSION

The selective fidelity concept has served the training device community well. It has allowed us to cope with analytical, technological, and cost constraints and yet still produce many training devices that were effective. Unfortunately, there were also many training devices that did not allow their training audience to reach the training goal completely.

We believe that advances in psychology, engineering, and computer infrastructure will add significant capability in the training device developers' quest of achieving high levels of fidelity. In the future, very large numbers of real-world stimuli will be presented to trainees at affordable costs. Presenting this number to trainees in tasks involving significant amounts of hand-eye coordination (e.g., gunnery training, aircraft operations) has generally been possible in the past only at high cost. Even where the funds have been made available, selective fidelity has still been required because of our inability to define and present all the possible stimuli. Presenting high levels of fidelity to tactical trainees has really not been possible because of the costs required to replicate the numbers of training devices necessary for sound tactical training. A minimalist selective fidelity approach has therefore been used. We believe that will change in the future.

Gagne (1985) referred to internal and external conditions of learning. Internal conditions of learning are what the learner brings to the learning situation. These include: learning style, prerequisite knowledge and skills, motivation, and a host of other internal parameters. External conditions of learning are the parts of the learning system outside of the trainee. These are the elements that we as instructional designers choose and arrange to present learning information to the trainee. All instructional matter and the media to deliver it (including training devices) are external conditions of learning.

In our quest to identify the key training stimuli, we should start with understanding the trainees' internal conditions of learning. Only then can we select and arrange the external conditions in an optimal fashion. The advances discussed in this report will all make it easier to focus on the learners and their internal conditions than has been the case in the past. Cognitive learning and performance theories/tools will give us a better perspective on those internal conditions and thus the stimuli that will need to be presented. Technological advances will make it easier and more affordable to simulate the stimuli that we decide the learner needs. That is not to say that the concept of selective fidelity will disappear. The nature of our selectivity will change. It will then be centered around the trainees' ability to absorb stimuli rather than other factors.

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