Virtual Time: Adding the Fourth Dimension to Virtual Reality

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The Virtual Time (VT) concept is an unique new manipulation of time in the context of Virtual Reality. VT refers to a Virtual Reality paradigm that manipulates time under the control of the operator, instructor, or software. Current Virtual Reality environments allow operators to control space. Virtual Time extends operator control to vary the flow of "simulated time", that is, "Time-Warp" the virtual environment. A hypothesis of the immersive nature of Virtual Reality which tightly binds an individual's "time norm" to the speed of environmental cues is presented and provides the framework within which to define the VT concept. The pilot study presented in this paper can also be characterized as the first use and extension of the Above Real-Time Training (ARTT) paradigm. In this application of Virtual Time, twenty-eight university students performed a simple tracking and targeting task under two levels of time compression, (i.e., 1.0x, 1.7x). All subjects were then tested in a real-time (1.0x) environment. This study investigated a virtual block grabbing task. The block moved in a three dimensional virtual environment and subjects were required to use a Virtual Reality glove to track and grab the block. In the block grab task the mean performance for the VT (1.7x) trained group performed twice as fast as the control group (1.0x) during testing (transfer of training) when both groups were tested at real time. Post test, a set of questionnaires were administered to subjects in order to establish the perceived temporal and workload demands of the task. The results from these questionnaires indicated that within both subject groups (1.0x and 1.7x), there were no significant differences detected between the perceived temporal and mental demands of the testing and training phases. This indicates that the VT group did not perceive the change in temporal demands between the training (1.7x) and the testing (1.0x) phases. There were, however, significant differences in the perceived temporal demands between subject groups. The VT group perceived less temporal demands during the testing (1.0x) phase than the control group. These results indicate that VT is a potential means of exploiting an existing ability of humans (time adaptability) within virtual training environments in order to achieve performance enhancement in real-time situations. ARTT analogies and parallel concepts are discussed including a synthesis of multi disciplinary support for Virtual Time. Conclusions and novel future research directions are presented.

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INTRODUCTION

The Virtual Time (VT) concept is a unique new manipulation of time in the context of Virtual Reality. VT *refers to a Virtual Reality (VR) paradigm* that manipulates time under the control of the operator, instructor, or software. Current Virtual Reality environments allow operators to control space. Virtual Time extends operator control to vary the flow of "simulated time", that is, "Time-Warp" the virtual environment. This pilot study can be characterized as the first use and extension of the Above Real-Time Training (ARTT) paradigm, to a Virtual Reality environment (Guckenberger,et al, 1992). Prior successful research results with ARTT on simulators encouraged the extension of time manipulation to a Virtual Reality environment. The hypothesis of this study is that the immersive nature of virtual environments will bind an individual's time norm to the speed of environmental cues presented in the VR environment.

In prior research using ARTT on tank gunnery, *(Guckenberger, et al, 1992), post test questions* indicated that subjects were unable to distinguish time compression changes during the experiment. Subjects were unable to distinguish changing from a 1.0x to a 1.7x condition and were also unable to distinguish a 1.7x from a 2.0x condition. Additionally, post test *comments from an ARTT study with US Air Force pilots* on part task F-16 trainers further supported the hypothesis that subjects are unable to distinguish between less than 2X changes in time compression. Both of these studies measured the perceived temporal demands via an informal- post-task query.

An attempt was made in this study to use well established and validated scales to measure perceived temporal demands and to determine if the time norm hypothesis extends to the virtual environment.

BACKGROUND

There is a growing body of research showing the "Time Adaptability" of Man (Holubar, 1962, Kolf, 1973, Hoey, 1976, Vidulich, 1983, Matin & Boff, 1988, Guckenberger, et al, 1992). Virtual Time (VT) is a method of exploiting an existing ability of humans (time adaptability) with existing capacity in Virtual Reality environments (i.e. software only changes to virtual form and function). The VT concept can be characterized as a synthesis of emerging man-machine interface technologies that manipulate time (i.e., RAP-COM, ARTT). Virtual time investigations are based upon human time perception and can be viewed as an extension of Above Real-Time Training research.

Psychophysical research into time perception has shown the relativistic nature of time perception in humans. (Jones, 1976, Toumodge, 1990, and Skelly, 1993). Relativistic nature is defined as linking an individual's perception of time to his/her "stimulation state" or "time norm". This is analogous to Einstein's theory of special relativity which links relative velocities *to a particular observer's frame of reference. It is* noteworthy that this analogy was arrived at independently by individuals in three different fields (Jones, 1976, Toumodge, 1990, and Guckenberger, et al, 1992). Working models of relative perception in audio training have been proposed (Hahn & Jones, 1981). *Current work is being done to extend these* audio findings to the arena of visual training (Skelly, 1993, Guckenberger, et al, 1992). These studies provide VT and ARTT with a firm theoretical basis upon which to build. These studies indicate that time perception can be altered if a particularly boring or interesting task is introduced, or if the arousal state of the subject is changed through external environmental cues (Parasuraman, 1986). Humans perceive time differently depending upon the individual's "stimulation state" or "time norm". This stimulation state is based, in part, on the sensory cues in the environment and the interactivity level between the individual and his or her environment.

Virtual environments, multi-sensory worlds which can be manipulated by users, provide highly interactive experiences. It is therefore reasonable to suggest that the *immersive nature of* Virtual Reality, coupled with virtual time, can alter an individual's "stimulation state" or "time norm". It is also suggested that the resulting *perception of time elicited by a particular stimulation* state forms a "time frame of reference" for that individual. If the stimulation environment is altered, *the individual's time frame of reference* will correspondingly recalibrate (without the individuals conscious awareness) in order to accommodate the *new time demands of the environment.*

When an individual's subjective time reference is *perceived as long, it may offer a unique advantage for* providing training on critical high performance skills. This artificially accelerated frame of reference may give *the operator more "perceived time" in which to actually* perform key elements of the mission. It may be suggested that the very perception (i.e. realization) *that the operator has more time may lead to better* decision making and situational awareness. It may give the operator the edge that makes the difference *in today's modern battlefield. Due to the fact that* VT training occurs in the same exact environment as real-time testing (i.e., the task stimuli and required *responses are the same; time is the only variable* manipulated), no negative transfer should be expected (Holding, 1965). In fact, due to the similarity between the *task stimuli and required responses, a high* transfer between training and testing should be expected. This means that more economic training can occur on existing VR simulators *by accelerating* the internal time flow. The simplest case for VT is improved VR simulator usage either by more trials per unit time per trainee, *or higher trainee throughput.*

ARTT HISTORY

Time compression has been studied with ARTT in flight simulators. Above-Real-Time Training (ARTT), refers to a training paradigm that places the operator in a simulated environment that functions at faster than normal time. In the case of air combat maneuvering, a successful tactical air intercept which might normally take five minutes, would be compressed into two or three minutes. All operations of the intercept would correspondingly be accelerated such as airspeed, turn and bank velocities, weapons flyout, and performance of the adversary. In the presence of these time constraints, the pilot would be required to perform the same mission tasks to the same performance criteria--as he would in a real time environment. Such a training paradigm represents a departure from the intuitive, but not often supported, feeling that the best practice is determined by the training environment with the highest fidelity. ARTT has been implemented economically on existing simulators. It is important to realize that ARTT applications require the simulated velocity of the targets and other entities to increase, NOT the update rate. Over 25 years ago, NASA flight test engineers recognized that if one could program a simulator to operate in "fast time", one could give test pilots a more accurate experience or "feel" of real-word stresses that would be present in the aircraft (Kolf 1973, Hoey 1976).

The origin of support for ARTT, in simulators, comes from anecdotal reports from NASA. Researchers at the NASA Dryden Flight Research Center during the X-15 *program in the late* 1960's needed a mechanism to address the X-15 test pilots' post flight comments of being "always behind the airplane..." and "... never *catching up*" (Thompson, 1965). Clearly, there were some differences between the perceived time in the well-practiced simulator flights and perceived time in *the experimental aircraft.* The first time NASA used fast time simulation was toward the end of the X-15 program. Pilots compared practice runs at various *time constants with flights they had already flown.* A fast time constant of 1.5x felt closest to their flight experience and was planned on being implemented in *the lifting body programs. Lack of funding precluded* the program from fully developing the capability, however, NASA's test pilots at DFRC have endorsed the *benefits of using "fast time" simulation as part of the* training process (Kolf 1973, Hoey 1976).

Past studies (Vidulich, Yeh, and Schneider, 1983) have examined the utility of time compression as an aid for training a basic air traffic control skill (a high performance *skill*). One group practiced intercepting an aircraft with the target plane traveling at 260 knots. The second group practiced the intercept at 5200 knots - 20 times real time! The subjects in the in the 260 knot group received 5-6 trials per hour during training, while those in the 5200 knott group received between 72-80 trials per hour. Both groups were then tested in real time.

The time compressed group was significantly better at identifying the turn point (i.e., the point at which the air traffic controller commands a turn in order to intercept an aircraft); there was no difference between groups on estimating roll out heading for the intercept.

Researchers at ECC and the University of Central Florida (Guckenberger, et al 1992) used a table top tank gunnery simulator to train subjects on three tank gunnery scenarios under five acceleration factors (i.e., 1.0x, 1.5x, 2.0x, sequential, and mixed). The results of this study demonstrated that training time could be cut up to 50%, with performance staying equal to (sequential, 1.5x) or surpassing (mixed, 2.0x) a real-time control group (1.0x). Further, in one ARTT group (mixed presentation) the mean performance score were 50% higher than the control group (1.0X). Another study (Guckenberger, et al 1993), used ARTT on F-16 part-task simulators and produced a 28% increase in the accuracy of performing emergency procedures by USAF pilots.

RESEARCH OBJECTIVES AND HYPOTHESES

The objectives of this study was to conduct research *regarding:*

1. The relative effectiveness of virtual time training versus conventional training in the same virtual environment. Specifically, this study attempts to systematically measure the benefits of Above Real-Time Training to subjects when they are transferred to real time testing conditions in a Virtual Reality environment.

2. The time adaptability of humans, that is, changes in time compression conditions of virtual time are mirrored by human time adaptability so that subjects are unable to differentiate between different time acceleration conditions. Specifically, this study attempts to measure the perceived workload demands of individuals in VT and real-time settings using well established and validated methods.

Based on prior research (Vidulich, Yeh, and Schneider, 1983, Guckenberger, et al, 1992, 1993), it was expected that training in a time accelerated environment would lead to poor performance versus a control group during training, but would lead to greater performance on a real-time transfer task . Second, based on the post test comments in prior ARTT studies (Guckenberger, et al, 1992, 1993), it was expected that VT subjects would be unable to differentiate between varied time conditions. Finally, it was *expected that training under various time manipulations* would not lead to negative transfer of training to a real-time task.

METHOD

Subjects

Twenty-eight university students served as subjects for this experiment. All subjects were recruited on a voluntary basis in accordance with American Psychological Association (APA) Principles for Research with Human Subjects. Prior to testing subjects were given written instructions informing them as to the general nature of the experiment.

Equipment and Materials

The experiment was run on a Virtual Environment testbed developed at the Institute for Simulation and Training and funded by ARI (Army Research Institute). The test-bed incorporates two 486-50 PC's with Intel DVI2 video cards, a Polhemus Fastrak with three sensors installed, a Virtual Research Helmet Mounted Display (HMD), a custom designed rapid gesture recognition glove (ChordGloves*), and a drafting table. The software was developed using the WorldToolKit library from Sense8 Corporation.

The Fastrak source was mounted and centered in the back of the drafting table. Two Fastrak sensors were used for viewpoint and right hand tracking. The viewpoint sensor was mounted on the front of the HMD with tip offsets adjusted to report values exactly at the center of the eyes. The hand sensor was mounted on the top of the ChordGlove and tip offsets were calibrated to report values at the point where the thumb and forefinger touch in a pinching gesture.

All viewing parameters were carefully calibrated to insure a one to one mapping between the drafting table in the real world and a model of the table in the virtual world. Standard WorldToolKit functions for parallax, convergence and Fastrak sensors were modified to improve this mapping. Sensor position and orientation from the hand sensor was directly coupled to a jack shaped cursor and acted as a 3D mouse.

Pinching contacts between the fingers and thumb, detected by the ChordGloves caused a cursor color change and, represented mouse button events.

Procedure

In this application of Virtual Time, twenty-eight subjects performed a simple tracking and targeting task under two levels of time compression, (i.e., 1.0x, 1.7x). All subjects were then tested in a real-time (1.0x) environment.

The individual subjects were asked to take a seat in a chair which had no wheels and move close enough to the drafting table so they could comfortably reach the top and center of the table. Subjects were given verbal instructions on what they were to look for in the virtual world. Subjects were informed that a 3D block would be moving back, forward left to right up and down while moving in a random 3D pattern. They were then instructed to place a glove onto their hand and a helmet was placed on their heads. Subjects were then told that the screen cursor represented a point between the forefinger and thumb. If they positioned the center of the crosshairs inside the target and pinched their thumb and forefinger together the target would disappear and end that trial. The subject's objective was to grab the virtual block as quickly as possible and each trial did not end until subjects successfully grabbed the block.

Each subject performed eighteen trials: Three familiarization trials, ten training trials and five testing (transfer of training) trials. Five subjects were randomly assigned to the Above Real-Time Training group (1.7x) and five to the control group (1.0x). Subjects were given the three familiarization trials at their assigned speed and then a one minute break. *Next the ten training trials began, again at the same* assigned speed. When this was complete, another one minute break was given. For the last five testing (for transfer of training) trials the control group was again tested at 1.0x, while the Above Real-Time VT group, who received training at 1.7x, was also tested at the 1.0x rate.

In order to determine if perceived workload demands were significantly different between the Above Real-Time VT group and the control groups three questionnaires were administered. These questionnaires were developed by modifying the Wewerinke (Wewerinke, 1974), which is a modified Copper-Harper scale (Cooper and Harper, 1969), and NASA Task Load Index (TLX) (Hart and Staveland, 1988) surveys. Both of these scales are well established and validated.

The modified Wewerinke scale (Wewerinke, 1974) was used as the basis for two questionnaires, one *measuring perceived temporal demands and the other* perceived mental demands. The temporal demand survey measured perceived temporal demands of the task on a scale ranging from 0- completely leisurely, very slow pace (i.e., an elderly person strolling through a park) to 9- frantic (i.e., the Olympic 100 meter dash). The mental demand survey measured perceived mental demands of the task on a scale ranging from 0- completely undemanding, very relaxed and comfortable (i.e., chewing gum) to 9- completely demanding (i.e., a time-pressured physics exam).

The modified NASA TLX scale (Hart and Staveland, 1988) was used to determine if there were any perceived differences in the following factors: mental, physical, and temporal demands, personal performance, frustration level, and effort level. The scale used to measure each of these factors ranged from Very Low (0) to Very High (100).

RESULTS

Raw performance data was collected after every trial. Summary data was then analyzed using a statistical T test. No significant difference was detected between the performance of the VT and control groups during both the training and testing phases. This is suggested to be due to the small sample size used for the study (n=28) and large variance in subjects initial VR skills. The trends in the data do, however, seem to *indicate benefits to the VT group during testing. The* mean of the 1.7x virtual time group (X=0.81 seconds, SD=0.73) was approximately fourty percent faster that of the control group (X=1.36 seconds, SD=1.42) during the testing phase (see Figure 1). The VT trend seems to indicate increased performance similar to prior ARTT studies (Guckenberger, et al 1992 1993).

This promising trend suggests further investigation is warranted.

The mean scores for both the real-time (1.0x) and the Virtual Time (1.7x) groups are tabled and graphically depicted on the following page.

Table 1 below depicts the means of both groups through all three phases of training (in Sec.).

	FAMILIARIZATION	TRAINING	TESTING
1.0x RT	3.78	1.94	1.36
1.7x VT	5.57	3.27	0.81

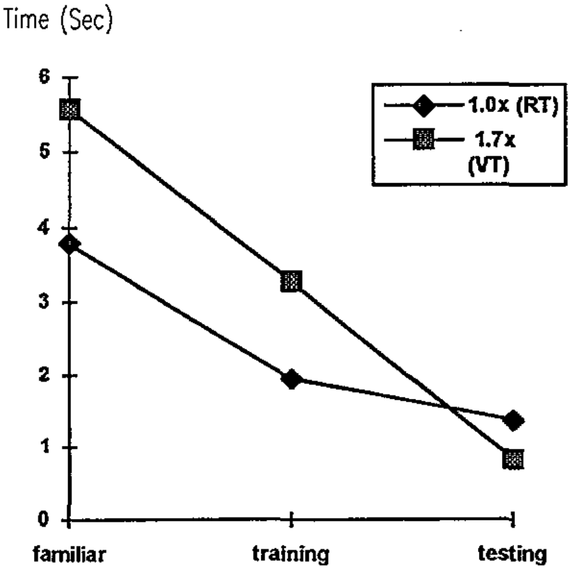

Figure 1: Descriptive statistics for the VT and Control groups through all three phases of training

Although the experiment did not detect any significant performance differences between the Above Real-Time VT and Control groups (which as aforementioned may be due to the power of the test) it would be beneficial to examine if there were any perceived workload differences between these two groups.

There were no significant differences detected in the perceived mental demands of the Above Real-Time VT group (training phase: X=3.8, SD=1.10; testing phase: X=3.3, SD=1.20) and the Control (training phase: X=3.7, SD=2.68; testing phase: X=4.0, SD=2.98,) groups (training phase : t=0.077, testing : t=0.487, neither of which are significant at the 0.1 level) using the modified Wewerinke scale.

For the training phase there were no significant differences detected in perceived temporal demands between the Above Real-Time VT group (X=4.6, SD=2.51) and Control (X=4.6, SD=1.14) groups (t=0) using the modified Wewerinke scale. For the testing phase, however, there was a significant difference in perceived temporal demands between the two subject groups. The Above Real-Time VT group (X=3.8, SD=1.10) perceived significantly less temporal demands that the Control group (X=5.6, SD=1.52) during the testing phase (t=2.15, which is significant at the 0.1 level).

The results form the modified NASA TLX scale indicated that the only factor for which a significant difference was detected between the two groups was frustration level. The Control group (X=20, SD=19.04) perceived significantly less frustration that the Above Real-Time VT group (X=54, SD=27.93) during the training phase (t=2.249, which is significant at the 0.1 level)

These survey results indicate that the Above Real-Time VT group, by receiving training at above-real-time rates, tended to find testing at real-time rates less time pressured than the Control group, who received training at real-time rates. Whether this perceived difference in temporal demands translates into differences in performance has yet to be fully verified. The results do indicate, however, that the above-real-time training rates tend to elicit a higher level of frustration than real-time training rates.

These results suggest that the subjects were unable to distinguish when they were in 1.0x from the 1.7x Virtual Time environments. The questionnaires results thus support the hypothesis that subjects would be unable to differentiate between different time acceleration conditions.

CONCLUSIONS

Based upon the results of this pilot study, tasks that contain simple psychomotor components such as the virtual block grab task seem to benefit form virtual time training, at least in terms of a reduction in perceived temporal demands. The small sample size used in the study is suggested to be of insufficient resolution to show statistical significance in performance time, but the trends seem favorable (see Figure 1) and bear future investigation with larger population samples.

1) It was hypothesized that virtual time training would be more effective than conventional training in the same virtual environment. This study did not detect a significant difference in performance time between the two groups, *but did show the benefit of a significant* reduction in perceived temporal demands for the VT group as compared to the control group during testing. In addition, there were no differences detected in the perceived level of temporal demands within each subject group. This result validates the prior ARTT study post test comments regarding the inability of subjects to differentiate between varied time conditions.

2) It is interesting to note, that both subject groups (1.0x & 1.7x) verbally complained and accused the experiment administrator of "speeding up the blocks", and "making the test harder" after their first one minute rest period between familiarization and training. The time rate was constant for both groups going from familiarization to training! It is suggested that the one minute rest period in virtual "blank" space, with its lack of active environmental stimuli, slowed down a subject's time norm. It is further proposed that when subjects transitioned back into the virtual training environment, their time norm, which had been recalibrated to the "blank" state, was disturbed thus leading to a higher level of perceived temporal demands. This anecdotal evidence suggests that the transition time to readjust the time norm in this case was one (1) minute or less. Although the subjects' comments have no scientific weight, it bears remembering that the original ARTT application success was in response to anecdotal comments from NASA test pilots. The transition time between different time norms is thus of interest and should be a target of *future research efforts.*

Finally, as expected training under various time manipulations did not lead to any negative transfer of training to a real-time task (i.e., the VT group did not perform significantly slower than the control group during the testing phase). As aforementioned, this was expected due to the similarity in the task stimuli and response requirements of the training and testing phases (Holding, 1965).

A key finding was the significant differences in the perceived temporal demands between subject groups. The VT group perceived less temporal demands during the testing (1.0x) phase than the control group. These results indicate that **VT is a potential means of exploiting an existing ability of humans (time adaptability) within virtual training environments in order to achieve performance enhancement in real-time situations.** *Virtual Time as applied to the intrinsic* time adaptability of man is a vast new field of great potential.

It is worth noting that adding VT to an existing Virtual Reality environment for this experiment was a low cost software only change with the software modification requiring less that 6 man hours. The **low implementation cost and large potential benefits coupled with current economic conditions suggest VT as a timely solution.**

The research results from this experiment support the on going synthesis of ARTT or Fast-Time Simulation into a cohesive theory. The current theory schematic (i.e. Appendix A) below encapsulates the progression and evolution of ARTT theory into Virtual Time.

Future Research Directions

Near-term work will focus on expanding the application of VT for emergency procedure training. The Silicon Graphics FLIGHT, DOGFIGHT and Shadow simulations have been successfully altered to support faster than real time rates. Virtual environment versions of these simulations are already being developed on a variety of manufactures hardware and will be altered to show Virtual Time in flight simulation.

The overall aim of the VT concept is to exploit the time *adaptability of humans and foster a new way of* thinking about time manipulation in the human-machine interface. Future research directions include safety, education, medical, and entertainment applications. For example, it would be possible to increase the voice and data communication rate over a virtual network to allow crews or teams to train at faster that real-time rates. Time flow could be manipulated for the benefit of the trainee. New training methods that are *time flexible* would change the form, fit and function of the human-machine interface. Above Real-Time VT programs are initially planned in simulation and training with follow on efforts involving the use of VT in human-machine interfaces.

Emergency procedure training for pilots, both commercial and military is envisioned as the initial proving ground.

The use of Virtual Time to investigate the nature and limits to the time adaptability of man.

Research the transition time to change "time norm settings", investigate if the transition time is dependent on the difference in environmental time rate changes, or a fixed transition time unaffected by the amount of environmental time rate change.

VR emersive nature binds human's time norm even more tightly than conventional simulation.

REFERENCES

Cooper, G.E. and Harper, R.P. (1969). The use of pilot ratings in the evaluation of aircraft handling characteristics. Washington, D.C.: *NASA, Report* No. TN-D-5153.

Fraisse, P. (1984). Perception and estimation of time. In M.R. Rosenzweig & L.W. Porter (Eds). *Annual Review of Psychology, 35* 1-36.

Guckenberger, D., Ullano, K.C., & Lane, N.E (1992). *The application of above real-time training for simulators: Acquiring high performance skills.* Paper presented at the 14th Interservice/Industry Training Systems and Education Conference, San Antonio, TX.

Guckenberger, D., Ullano, K.C., & Lane, N.E. (1993). Training High Performance Skills Using Above Real-Time Training. *NASA Technical Report Contract NAG-2-750.*

Hart, S.G. and Staveland, L.E. (1988). *Development of NASA-TLX (Task Load Index)*: results of empirical and theoretical research. Amsterdam, Netherlands: North-Holland.

Hoey , R. G., (1976). *Time compression as a means for improving the value of training simulators. Unpublished manuscript.*

Hoffman, R.G., & Morrison, J.E. (1987). *Requirements for a device-based training and testing program for M1 gunnery. Volume 1: Rationale and summary of results* (Report No. FR-TRD-87-41). Alexandria, VA: Human Resources Research Organization.

Holding, D.H. (1965). Principles in training. Oxford, England: Pergamon.

Jones, Mari R. Time Our Lost Dimension *Psychology Review 1976* Vol. 83 (5) 323-355

Hahn J. & Jones M. J. (1981) Invariants in Auditory Frequency Relations, Scandinavian Journal of Psychology 22, 129-144.

Kolf, J. (1973). *Documentation of a simulator study of an altered time base* Unpublished manuscript.

Lane, N.E. (1987). *Skill acquisition rates and patterns: Issues and training implications* New York: Springer-Verlag.

Lee, T.D., & Magill, R.A. (1983). The locus of contextual interference in motor skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9* 730-746.

Matin, E., & Boff, K.R. (1988). Information transfer rate with serial and simultaneous visual display formats. *Human Factors* 30, 171-180.

Parasuraman, R. (1986). Vigilance, monitoring, and search. In K.R. Boff, L. Kaufman, & J.P. Thomas (Eds.), *Handbook of perception and human performance: Volume II: Cognitive processes and performance* (pp. 43-1 - 43-39). New York: Wiley.

Schneider, W. (1985). Training high performance skills: Fallacies and guidelines. *Human Factors 25* 285-300.

Shea, J.F., & Morgan, R.L. (1979). Contextual interference effects on the acquisition, retention and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory, 5* 179-187.

Shiffrin, R.M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84* 127-190.

Skelly, June J. (1993) *The Role of Event Time in Attending* Time & Society Vol. 2(1) , 107-128

SPSS, Inc. (1992). *SPSS for Windows* [Computer Program]. Chicago, IL: SPSS, Inc.

Stevens, S.S. (1975). *Psychophysics: Introduction to its perceptual, neural, and social prospects* New York: Wiley.

Thompson, M. (1965). *General review of piloting problems encountered during simulation flights of the X-15* Paper presented at the 9th Annual Meeting of the Society of Experimental Tests Pilots.

Toumodge, S.S. (1990) *Signal and Data Processing of Small Targets* Paper presented at the Orlando April 1990 Annual Meeting of the Society of Photo-Optical Instrumentation Engineers. (A91 - 36901 15-32) 378-385.

Vidulich, M., Yeh, Y.Y., & Schneider, W. (1983). *Time compressed components for air intercept control skills* Proceedings of the 27th meeting of the Human Factors Society. 161-164.

Wewerinke, P.H. (1974). Human operator workload for various control conditions. Wright-Patterson Air Force Base, OH, 10th NASA Annual Conference on Manual Control, 167-192.

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APPENDIX A Theory Schematic