THE IMPACT OF PICTORIAL DISPLAY ON OPERATOR LEARNING AND PERFORMANCE

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ABSTRACT

The objective of this study was to investigate the effects of pictorially displayed information on human learning and performance of a simple control task. The controlled system was a harmonic oscillator and the system response was displayed to subjects as either an animated pendulum or a horizontally moving dot. Results indicated that the pendulum display did not effect performance scores but did significantly effect the learning processes of individual operators. The subjects with the pendulum display demonstrated more veridical internal models early in the experiment and the manner in which their internal models were tuned with practice showed increased variability between subjects.

INTRODUCTION

The power of the computer has opened up a wide range of possibilities for displaying information to the human operator and there has been a considerable amount of research on the ergonomics of computer based displays. Intensity, color, and relative size are some of the variables which have been studied. Very little attention, however, has been paid to the effects of the representational form used to present information to the operator.

With the increased capabilities of computer graphics, the options available for pictorial representations are numerous. The state of a chemical process, for example, could be displayed by listing the information in alphanumeric form, drawing pictures of gauges, using coded schematics of the process, or using other pictorial animation.

The purpose of this research was to investigate the effects of the display form on operator performance and learning. A control task involving a simple undamped harmonic oscillator was used to compare two computer generated displays. The system was presented to different subject groups using either an abstract context-free display of a horizontally moving dot, or a pictorial representation of an oscillating pendulum, presumably a physical system with which most people are familar. The optimal control strategy was identical in each case. The fundamental question of interest was whether the pictorial representation of a system already familiar to the operator would effect his/her performance or behavior.

It is commonly accepted that humans form internal, cognitive representations or models of the "real world" around them. There is no evidence to indicate that these internal models are structurally equivalent to the usual representations of physical systems. Behavioral (input/output) equivalence does not neccessarily indicate structural equivalence. Rasmussen (1983), for example, explains the structures of these internal models on three distinct levels of complexity relating to skill, rule and knowledge based levels of performance. Most theories not only support structural differences but also contend that the human's internal model is often behaviorally non-veridical when compared to the physical system. Larkin (1982) argues that the structure of this internal representation can vary drastically between individuals. In her analysis of expert and naive subject behavior in solving physics problems she describes the internal representations of these two types of subjects as structually different. The expert's "physical representation" is composed of combinations of context-free entities such as forces and momenta. The "naive representation" uses such physical structures as springs, pulleys and blocks as the basic entities from which cognitive representations are formed. In this type of representation the attributes of the entities are influenced by the context in which they appear.

The human operator is assumed to use an internal representation of the system to choose the control actions exerted on a dynamic system. The operator is assumed to have a collection of cognitive representations for existing physical systems which have been built up by experience (i.e., models of pulleys, springs, pendulums, etc.). Therefore, one might expect that if the operator can use one of these existing models, adjustments to a new system can be made quickly by simply adjusting the parameters of this existing model. Pictorial display is one methodology that can be used to "lead" the operator to an existing internal model.

The task used in this study was the same for all subjects but the system was represented as a pendulum to some subjects while for other subjects it was simply a horizontally moving dot. The objective was to determine if performance or learning speed were improved for those subjects given a representational context for which an existing cognitive model of the system dynamics might already exist.

METHOD

Two independent representation variables: (1) pictorial description variations (dot, pendulum), and (2) repeated motion cue variations (repeat, no repeat) were used in this experiment. These independent representational variables were combined in a 2 X 2 combinatorial design, resulting in four pictorial displays: (1) dot display with no repeated motion (DN), (2) dot display with repeated motion (DR), (3) pendulum display with no repeated motion (PN), and (4) pendulum display with repeated motion (PR). Eleven subjects were run under the DN and PR conditions. These were the conditions which provided the operator with the most (PR) and least (DN) amount of information. Five subjects were run under conditions DR and PN.

Experiments were conducted in groups of five or six subjects. For each group, eight right-handed persons (four male, four female, all college students) were screened via a critical tracking task (Jex, McDonnell, and Phatak, 1966) and the five best performers (six best in the two final groups) were selected for the experiment. All subjects were paid $3.00 per day, and an incentive prize of $10.00 was awarded to the subject in each group with the best average score at the end of the ten sessions.

A total of 32 subjects participated in the experiment; two conditions with five subjects each and two conditions with eleven subjects each.

The controlled system was an undamped harmonic oscillator. The equation of motion for this system was as follows:

$$d^2x(t)/dt^2 = -0.16x(t) \pm 0.7112$$

The variable t denotes time in seconds and x(t) the position of the system measured in centimeters. The natural frequency of oscillation of this system is 0.4 radians per second. The term ± 0.7112 defines the two control forces which the operator could use. By pushing a button the operator could switch from the +0.7112 force to the negative one.

The undamped harmonic oscillator system was simulated on a DEC PDP 11/34 digital computer and displayed with a Raster Technology Model One 512 x 512 resolution raster graphics controller. Pixel images were displayed on a Mitsubishi Model C3419 color graphics monitor. The display was viewed on a 29.3 cm x 29.3 cm area with a display grain of approximately 17.5 pixels (or points) per centimeter and was updated at a 30 hertz refresh rate. Subjects were seated 80 cm from the screen and wore headphones over which background white noise was transmitted. The white noise was briefly interrupted prior to each trial with a 80 db tone for 200 milliseconds to signal the beginning of the next trial.

The system was displayed as a yellow dot 0.69 cm in diameter and the target was displayed as a 1.14 cm red vertical line at the center of the screen. The pendulum display differed from the dot display by drawing a yellow line connecting the center of the dot to an off-screen point 85 cm above the target which represented the center of oscillation. Motion was displayed on the arc formed from this 85 cm radius, causing a slight vertical displacement of the pendulum which reached a maximum of 0.5cm at the extremes of the dot path.

Each trial was initiated with a rightward force applied to the yellow dot (pendulum), with the dot (pendulum) moving to the left. The subject's task was to reverse the rightward force to a leftward force at the point which caused the dot (pendulum) to reach zero velocity at the target. The task was therefore equivalent to a time optimal control problem. The subjects could reverse the applied force by pressing a button with their right index finger. The button was located on an inclined board attached to the right arm of the subjects' chair. A red arrow was displayed on the screen to indicate the direction of the applied force. The magnitude of the force was constant and uneffected by how hard or how long the button was pressed.

After the force was switched the dot (pendulum) continued its rightward motion until it reached zero velocity. At this point the absolute value of the distance from the dot to the target was displayed to the subject as a score for that trial. In cases where no repeated motion was displayed the dot (pendulum) then disappeared from the screen. When repeated motion was displayed the dot (pendulum) continued its motion on the switched trajectory for another full cycle (15.7 seconds) and disappeared when it reached the rightmost position for the second time. If a subject used the well known (Athans and Falb, 1966) time optimal control strategy for this system, the score would be zero.

The subjects participated in one session per day for 10 days. Each session consisted of 84 trials, preceded by 2 additional practice trials. Subjects were given instructions prior to the first session. The 84 trials corresponded to 84 distinct system initial conditions, 7 each on 12 distinct orbits in the phase plane. The initial conditions are shown in Figure 1. The 84 initial conditions for the trials were randomly ordered each day for each subject. Each trial commenced with the word "ready" displayed for 1.5 seconds. The screen was then blanked, and 0.5 seconds later a tone was transmitted over the headphones. At this instant the 0.69 cm

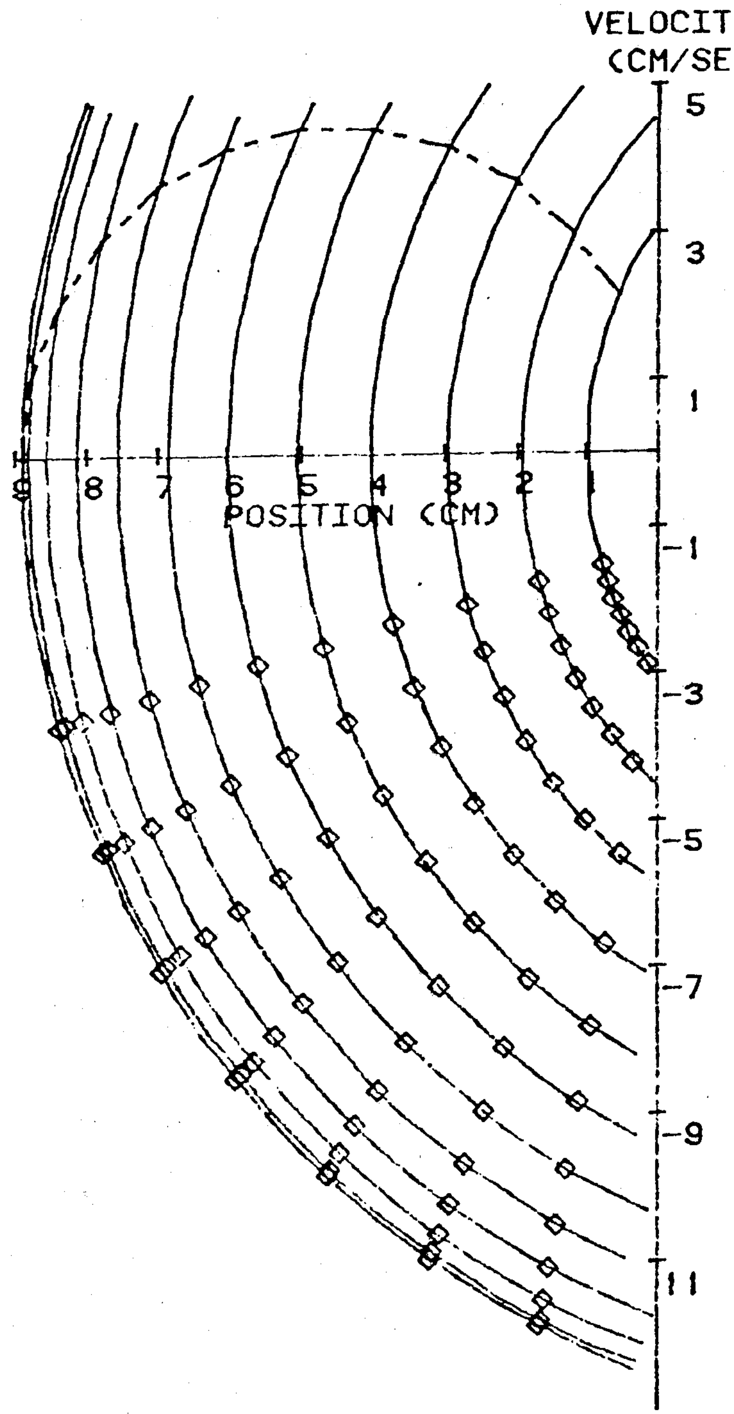

Figure 1

Initial Conditions Used in the Experiment diameter dot also appeared on the screen, and the trial began. There was a 5.0 second pause between trials and a two minute rest break after the first 42 trials. Subjects were given 10 seconds to make the force switch. If a subject did not respond within that time limit he/she was alerted by the appearance of the word "timeout" on the screen. The trial was then terminated and a maximum score of 1400 (i.e., 14 cm) was recorded for that subject during that trial.

In addition to feedback scores on each trial, subjects were shown their average score for that session at the end of each session. A graph of these average scores over previous sessions was displayed at the beginning and end of each session. The data recorded for each trial included the initial position and velocity, the position and velocity of the system at the time of the switch, and the switch time measured from the start of the trial.

RESULTS

An initial analysis of performance based on five subjects per group showed that the largest differences occurred between subjects given the most information (pendulum, repeat), and subjects given the least amount of information (dot, no repeat). The sample size for these two conditions was increased to eleven and the analysis was focused on these two conditions. For the purpose the following discussion the group exposed to the pendulum, repeat (PR) condition is refered to as the "pendulum" group and the group exposed to the dot, no repeat (DN) condition is refered to as the "dot" group.

One subject dropped out after three days and was excluded from the analysis. Three subjects, one under the DN condition and two under the PR condition, had an initial basic misunderstanding of the task. This misunderstanding was common to all three subjects. In these three cases, subjects switched the force very early in the trial, while the system was still moving in the leftward direction. These subjects therefore did not have the opportunity to observe the basic oscillatory characteristics of the system, and did not learn for many trials that the direction of motion would reverse at some point even if the leftward force was not applied. All subjects eventually learned this and changed their strategy to allow the system to continue its leftward motion to the turnaround point prior to switching the force. This change in strategy usually occurred several sessions into the experiment, making the comparison of groups on a session by session basis difficult since the impact on learning during these early sessions is not known. Therefore, the data from these subjects were not included in the analysis.

The criterion used to reject a subject data set required the median locus of switch points to reside entirely in the third quadrant of the phase plane for at least one session. If a subject's performance met this criterion for one session all the data for that subject was omitted from the analysis. Figure 2 contains a phase plane example which met the rejection criterian.

The most obvious evaluation of the effect of the pictorial display on performance is through comparison of the operator feedback scores. Each subject was given a session score which corresponded to the mean of the 84 trial scores for that session.

An analysis of variance was performed for each session comparing the subject session scores of the different groups. While no significant differences were found between the pendulum and dot groups on any day of the 10 days, the mean group score of the dot group was below that of the pendulum group for all 10 days. The lack of statistical significance can be primarily attributed to the high degree of variability from subject to subject. A plot of the mean scores of the groups for successive sessions is presented in Figure 3.

Although the above comparison of operator feedback scores serves as an indication of overall performance in achieving the goal of the task, it gives no insight into the behavioral patterns of performance and how they are effected by the pictorial display. To further investigate the behaviorial differences between groups a more in depth phase plane analysis of switching behavior was conducted.

Phase Plane Analysis of Performance

The 84 initial conditions used during each session were composed of seven points on each of 12 system trajectories or orbits. Since the seven initial conditions lying on a given orbit have the same optimal switch point, the median switching point was calculated from the seven actual operator switching points on each system orbit to obtain a total of 12 median switching points for each day's performance for each subject. This median switching behavior was compared with the optimal behavior on an orbit by orbit basis. This is illustrated in Figure 4 where the locus of median switching points are depicted as data points on each orbit, and the optimal switch curve is displayed as a dashed line.

Any non-optimal switch places the system on a trajectory that reaches zero velocity at some point other than the origin, i.e., the system either undershoots or overshoots the target. In the phase plane, any such trajectory is represented by a circle with center (-4.445,0.0) and a radius either larger (overshoot) or smaller (undershoot) than the optimal 4.445. The difference between the radii of the switch-

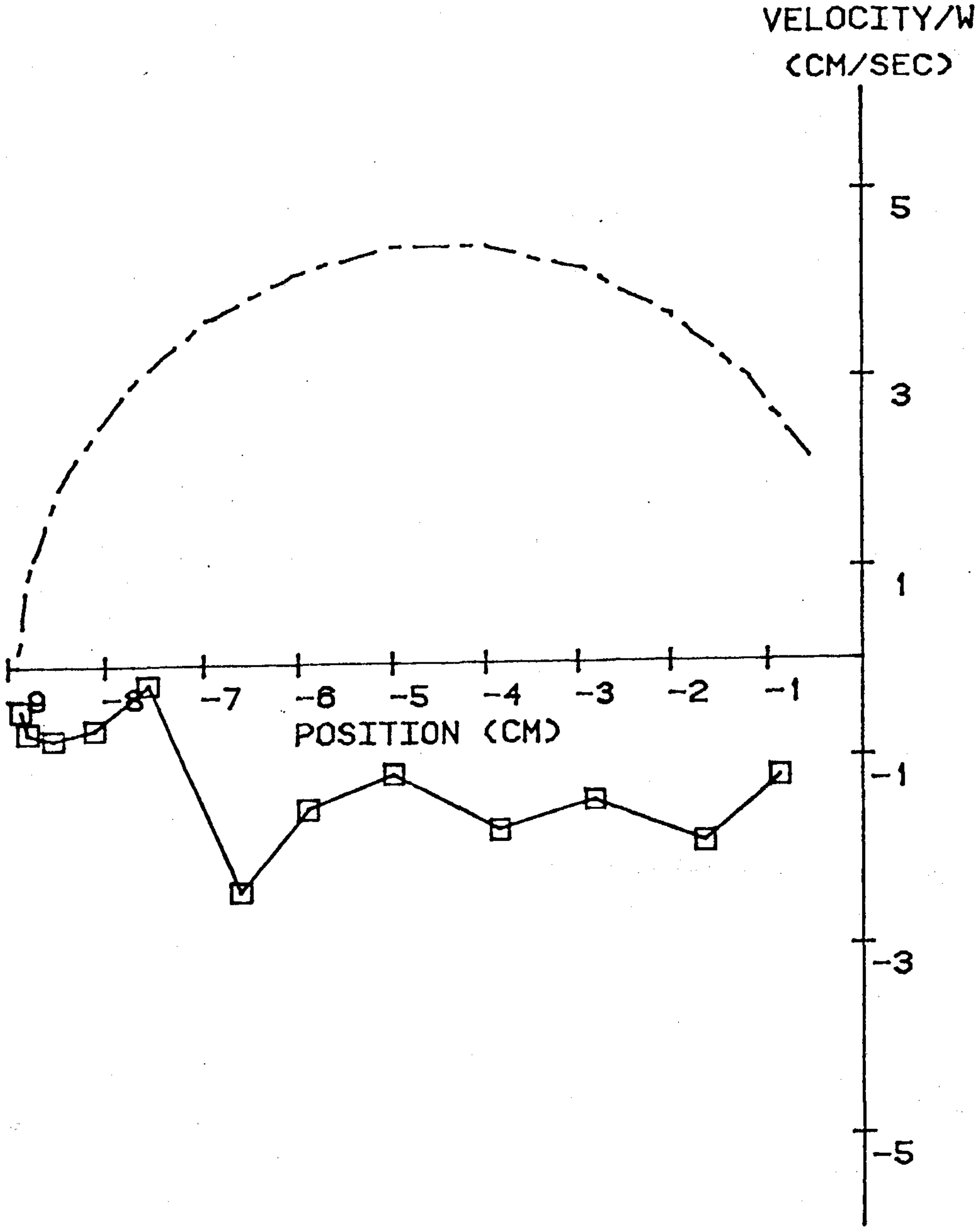

Figure 2

Subject Response Meeting the Rejection Criterion

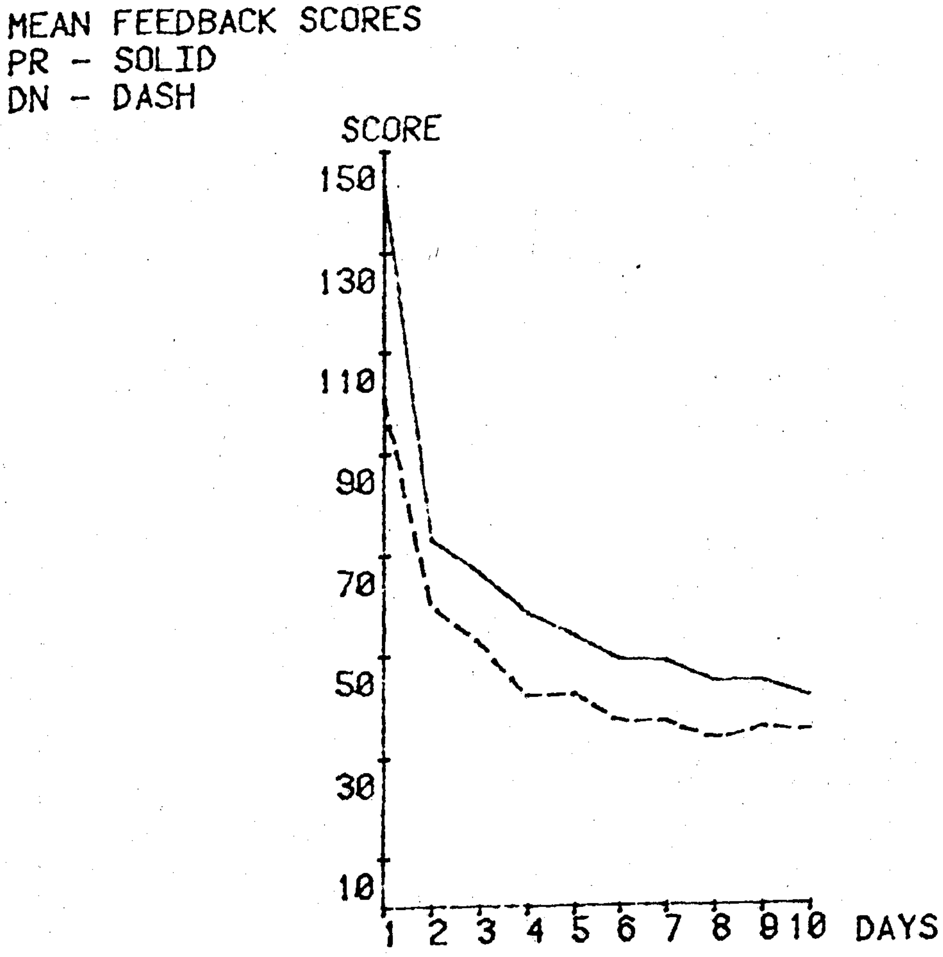

Figure 3

Average Scores by Group and Day

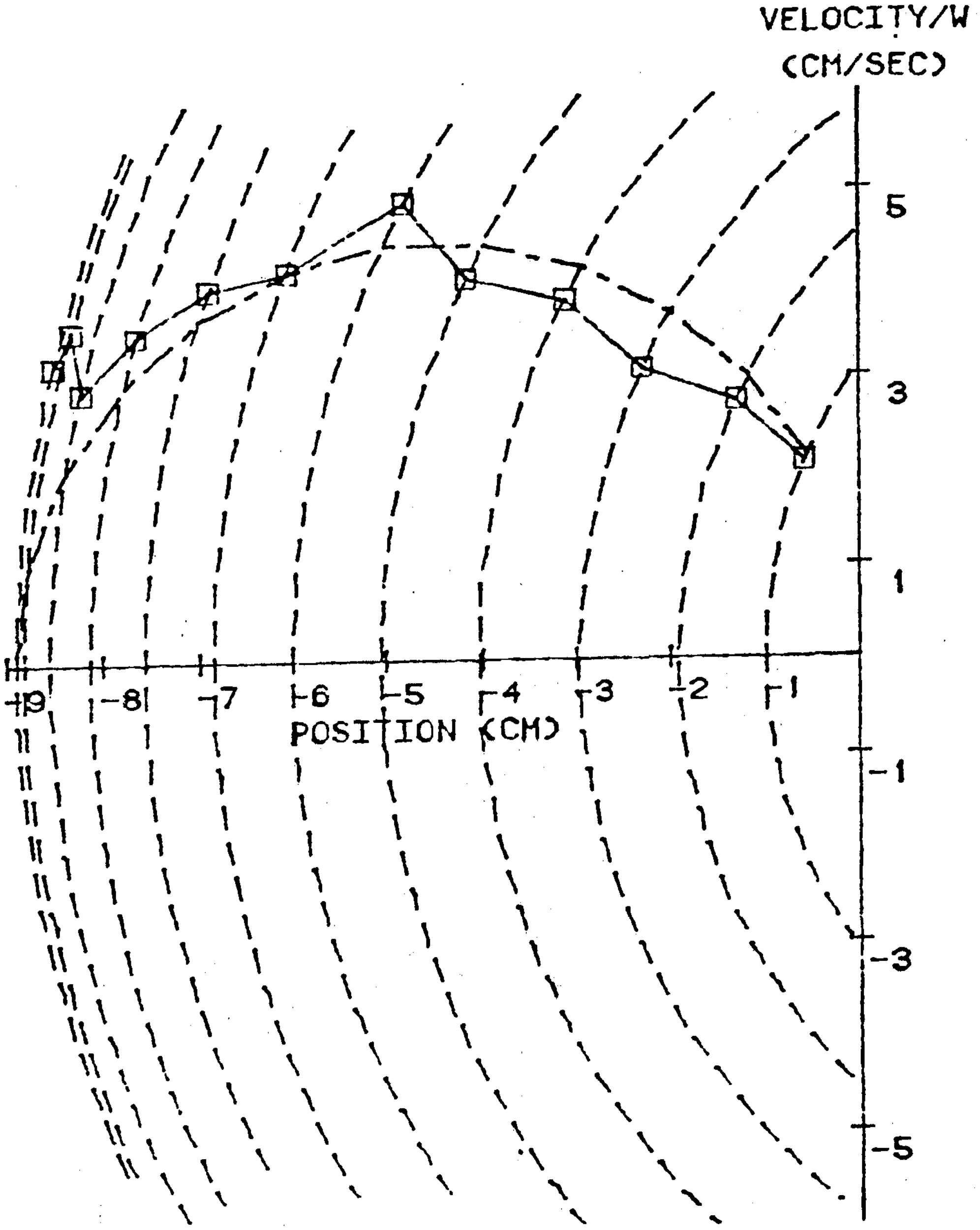

Figure 4

A Typical Subject Switch Locus
Compared With the Optimal Switch Curve

ing trajectory and the optimal trajectory was used as a measure of switching error for each orbit. Negative radial error thus indicated an early switch and target undershoot, while positive radial error indicated a late switch and target overshoot. The feedback score displayed after each trial was the absolute value of this measure multiplied by one hundred.

Typical operator behavior was characterized by early switching on the inner orbits and late switching on the outer orbits. An analysis of variance was performed on the inner orbits (1-5) and outer orbits (6-12), separately. Using radial error as the dependent variable and orbits as a within subject variable, analyses of variance were performed comparing the two groups on each day. These analyses showed no significant difference between groups for the inner orbits on any day. A marginally significant difference ($p < 0.10$) was found on the tenth day only for the outer orbits.

As a measure of intraorbit variation the time spread among the seven switches for each orbit was measured after the extreme high and low point were removed. The measure used was the angle in the phase plane between the second and sixth ordered switching point on each orbit, which is proportional to the time between these switching points. This temporal range was used as the dependent variable in comparing the two groups for the inner and outer orbits. Although the mean range for the pendulum group was consistently higher, no significant difference was found between the two groups.

Operator Internal Model Development

In order to investigate the more subtle effects of pictorial display on operator behavior, the phase phase switching locus was used to infer an operator's internal model of the system for each session. The change in these models was used to analyze the effect of the pictorial display on the orderly change of that model over time. The concept and development of the internal model used here is discussed in detail by Jagacinski and Miller (1978). A brief summary will be provided below.

Optimal performance requires switching the force when the system state lies on the trajectory which passes through the origin. If one assumes that the subject switches when he/she judges that the system state is on this trajectory, then the locus of operator switch points can be used to estimate the subject's cognitive characterization of the dynamics of the system. Assuming that the operator is behaving in accordance with some internal model he has developed of the system, the switching point locus could be described as a sampling from the trajectory of that model. The form of this cognitive model is certainly not clear and so an assumed form must be used. The form chosen by Jagacinski and Miller

(1978) and used in the present analysis is a second order differential equation of the form

$$a(t) = B0 + B1x(t) + B2v(t)$$

where a(t), v(t), and x(t) are respectively acceleration, velocity and position as functions of time, t. B0, B1, and B2 are constants.

Estimates of B0, B1, and B2 were obtained using an algorithm which fit a curve of the above form to the locus of the subject's 12 switch points for that session. The result was a parametrically determined description of the subject's internal model of the system for that day.

This alogorithm searched through the eigenvalue space of the system. The eigenvalues searches were conducted separately for zero (constant acceleration), real, and complex eigenvalues. The measurement used for determining the best fit was the sum of squared error between model and data. Error was defined as the Euclidean distance in the position, velocity plane with position expressed in centimeters and velocity expressed in centimeters per second. With the exception of Day 1, the sum of squared error estimates were consistently under 1.0, and normally under 0.5. These low error measures indicated that the estimates obtained for the three parameters B0, B1, and B2 reflected a reasonably accurate modeling of the 12 point switching loci.

The estimates of B0, B1 and B2 parameters can be used to interpret an operator's behavior. For example, early in practice the subjects exhibited low negative values of the B0 parameter. This trend indicates that the operator behaved as if the external force was stronger than it actually was. Similarly the positive B2 values which were found throughout practice indicate that the operator behaved as if there were a positive force proportional to velocity which caused a high decceleration rate for high positive velocities with this force decreasing as the velocities decreased. In other words, the subjects behaved as if there were a force related to velocity which caused the system to "slow down" faster at higher velocities than was actually the case.

To determine the change of the internal model for each group with practice, a regression analysis was performed on each parameter, fitting the parameter estimates to a quadratic function of days. The dot group showed a significant effect of days ($p < 0.001$) for all three parameter estimates, while the pendulum group did not show a significant day effect for any of the three parameters.

While the group means of the three parameters were never veridical, the progression of the parameters in both groups moved toward their veridical values over time. Figure 5 is a graph of group parameter means by day. For example, the dot group had a group mean value for B0 of -1.68 on Day 2 and -1.28 on Day 10, thus changing with practice toward the veridical value of -0.7112. Similarly, the pendulum group went from -1.51 on Day 2 to -1.25 on Day 10 for this same parameter. For all three parameters the pendulum group began the sessions with mean parameter values which were closer to veridical than were the corresponding values for the dot group. This trend continued until Day 4 (Day 5 for the B1 parameter), when the difference between the two groups became negligible. By Day 10 the mean position and velocity parameter values for the dot group (B1 = - 0.150, B2 = 0.42) were slightly closer to veridical values than those for the pendulum group (B1 = - 0.146, B2 = 0.43). These differences are small however and not statistically significant.

In an attempt to characterize this significant effect of days on the DN group scatter plots of the parameter estimates were generated. Examination of these plots suggested a possible dichotomy in the data. There appeared to be a bipolar grouping of the data which was particularly evident in the B1 parameter fits. For this parameter most of the data points fell in the range from -0.1 to -0.3. However, there was a second significant clustering of data points about zero or slightly positive (< 0.1). Nearly all the data points fell into one of these two distinct groups. In an attempt to classify this distinction the eigenvalues of the model fits were compared. The B1 parameter fits which clustered around zero were characterized by model fits having two real eigenvalues with one of the eigenvalues either zero or very small (less than 0.1). This type of model fit is characterized in the phase plane as a trajectory which tends to "flatten out" as distance from the target increases and will be refered to as the Type I model.

The second clustering of points was characterized by model fits with either 1) complex eigenvalues or 2) positive real eigenvalues with values nearly equal (within 0.1). This type of model, which shall be refered to as the Type II model, demonstrates a degree of curvature in the phase plane. Since the eignenvalues for the system dynamics are complex (+0.4i, -0.4i) a Type II model fit is necessary to describe a veridical internal model of the system. Using this eigenvalue classification, all the models derived fell into one of these two model catagories.

The "flat" characteristics of the Type I model, as mentioned before, is an indication of the small B1 parameter. It is this parametric weight on position (often referred to as the spring constant) which provides the oscillatory or pendulumlike characteristics of the dynamics. An operator switch curve modeled with a Type I model can be interpreted

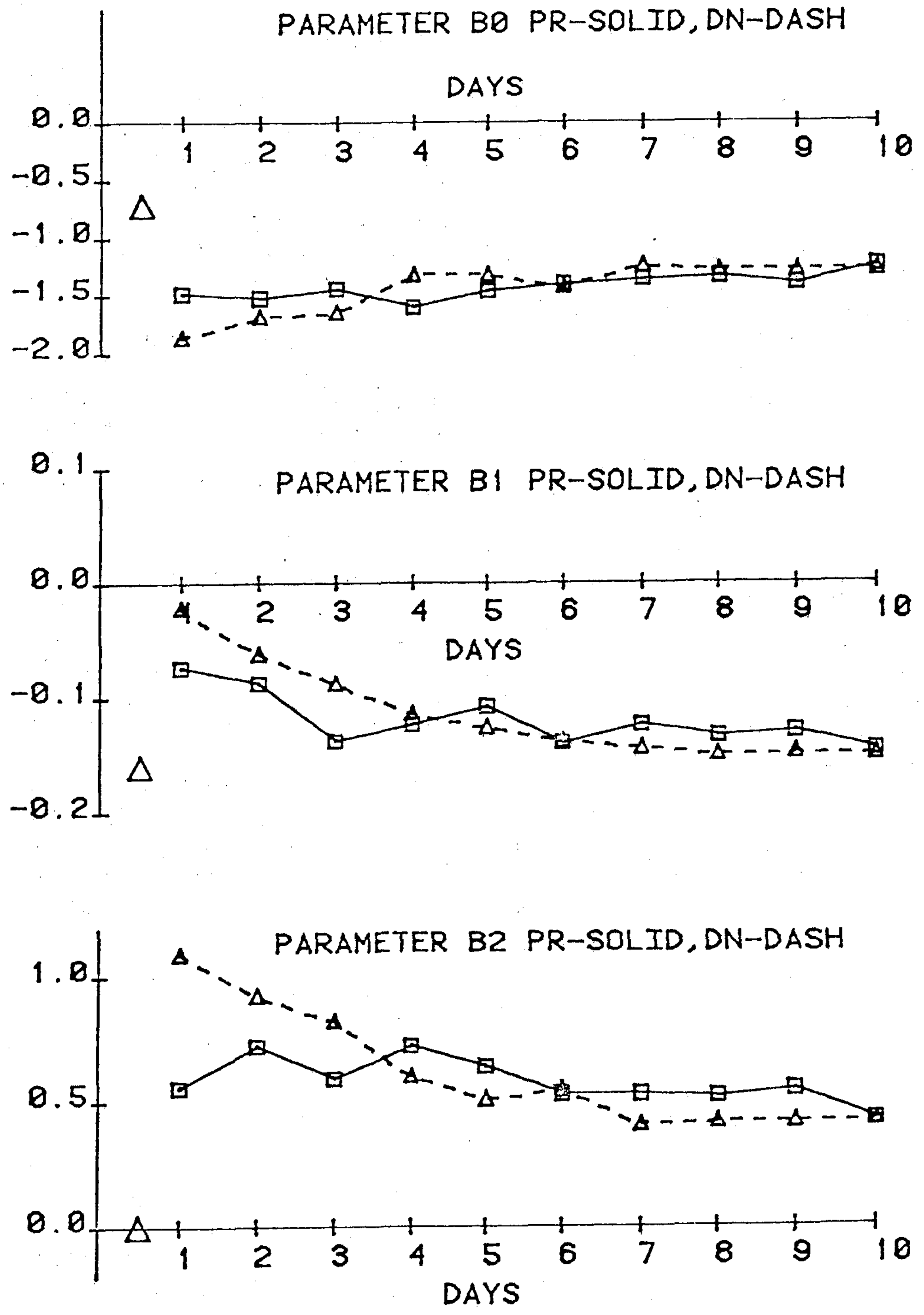

Figure 5

Average Parameter Values By Group and Day to indicate a failure on the part of the operator to recognize and interpret the oscillatory or pendulumlike characteristics of the system correctly. Conversely, a Type II model contains a much larger weighting on position and demonstrates more curvature in the phase plane. This type of model implies a more accurate interpretation of the system's oscillatory characteristics. Typically, operator switch curves were modeled with the Type I models early in practice and Type II models later. With only two exceptions, once the Type II model was fit to a subject's switch curve on a particular day all remaining days were also modeled with a Type II model. The exceptions were two subjects in the pendulum group which were modeled by Type II models one day early in practice (Day 1 for one subject and Day 2 for the other) and then not again until several days later in practice.

Transition from Type I model fits to Type II model fits occured at various stages in practice for different subjects. For each day, the subjects of each group were catagorized by the model type used to describe their internal representation of the system. Figure 6 shows the proportion of subjects in each group which were modeled by the Type II model. As this graph shows, a much higher percentage of subjects in the pendulum group were modeled with the Type II model initially. The portion of subjects from the dot group with this model while initially lower, increased over practice and was higher than the pendulum group by the fourth day of practice. By Day 10 all subjects were modeled with the Type II model. The largest dichotomy between the groups was on Day 1 where 5 of the 9 subjects from the pendulum group and only 2 of the 10 of the subjects from the dot group were modeled with the Type II model. The probability of at least this degree of spread between groups, assuming that the distribution of subjects in the two model types was independent of the group, was calculated directly from the binomial marginal probabilities. Since the number of pendulum subjects with Type II model is expected to be higher initially this can be considered a one tailed test. This probability was found to be significantly low ($p < 0.05$) indicating that the display type significantly effected the type of model generated on the first day of practice. There continued to be more subjects from the pendulum group in this model catagory until Day 4, however, the proportional differences between the groups were not significant after Day 1. These results suggest that the pendulum display aided the subjects in initially interpreting the oscillatory chacteristics of the system. It appeared to take the subjects given the dot display longer to recognize and interpret these characteristics and demonstrate behavior captured by Type II models.

The next step was to then compare the progession of the subject's internal model once it was modeled with a type II model. Given that the subject's performance indicated that

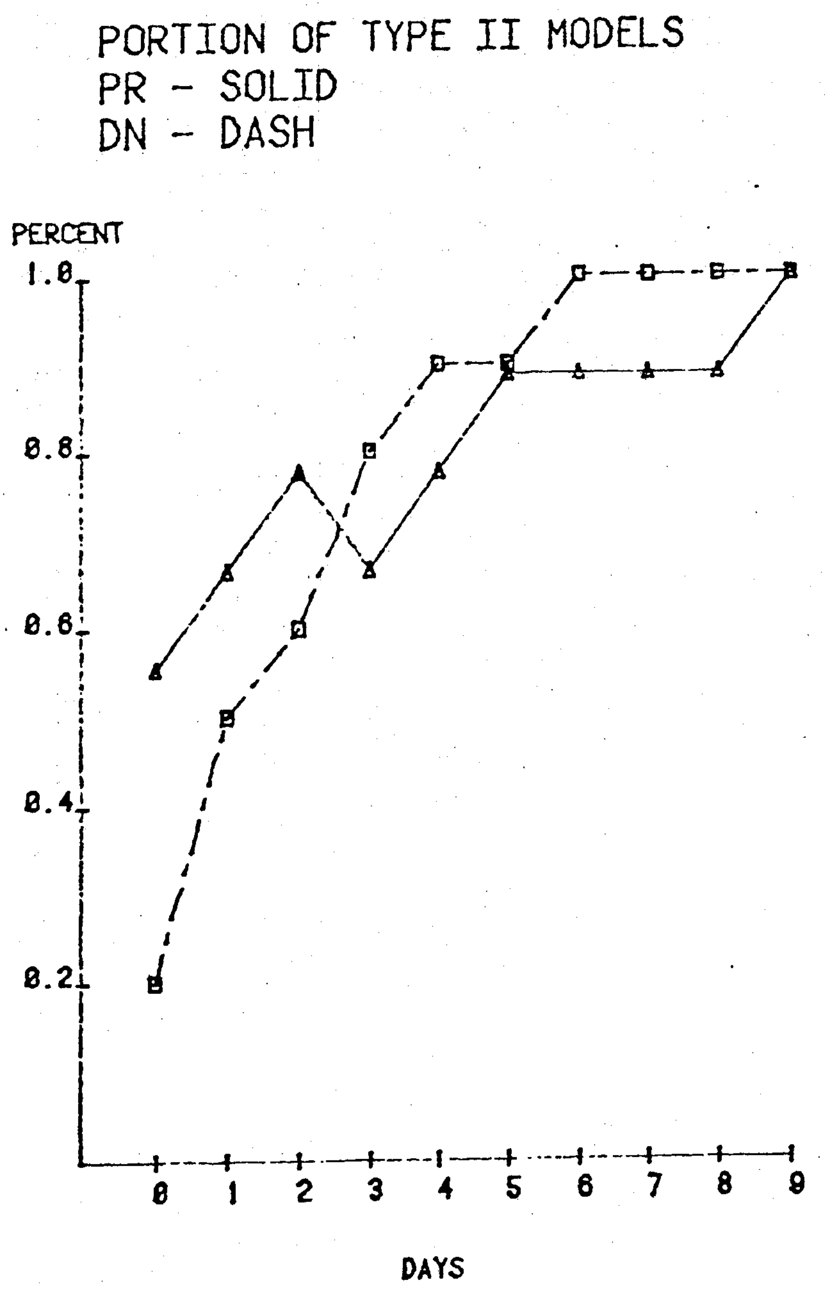

Figure 6

Proportion of Subjects
Represented by Each Model Type by Day

he/she was able to somewhat interpret the oscillatory characteristics of the system, how did the subject "tune" his/her model over practice and did the type of display effect this tuning process? A regression analysis was performed on the three Type II model parameters for each group. The results of this analysis showed significant subject differences in both groups in parameters B0 and B1 ($p < 0.001$). A significant subject effect was not found for the B2 parameter of the dot group. The subjects by day interaction effect was significant ($p < 0.05$) in all three parameters for the pendulum group. No significant subject by day interaction was found in the dot group. This indicates that for the pendulum group the parameters of the different subjects did not change in a uniform manner. This suggests that the manner in which subjects in this group tuned their model varied greatly and suggests that the use of the pendulum display resulted in greater individual differences in the way the subjects tuned their internal representations of the system with practice.

The dot group, however, showed a significant effect of day ($p < 0.001$) in the B1 parameter and no significant effect of subject by day interaction. This indicates that for the subjects in this group this parameter changed in a similiar manner with practice. Hence, one can conclude that once the subjects in the dot group begin to interpret the oscillatory chacteristics of the system (i.e., form a Type II model) it is primarily the B1 parameter, or spring constant, that characterizes the change in their model and that parameter changes in a similar manner for different subjects.

DISCUSSION

Certain assumptions are made when using the approach described in the previous section to describe the human operator's internal model of the system. The first assumption is that the operator's prediction of the motion of the system after the force is reversed can be described as a unique trajectory which passes through the origin of the phase plane. The concept of describing this trajectory with a differential equation is not new and has been used by Jagacinski and Miller (1978) with a similar control task as was used in the present case, and by Jagacinski, Johnson, and Miller (1982) in describing extrapolation performance. Through parameteric adjustment these internal models exhibited orderly changes with practice.

A second assumption of this approach is that the system is assumed to be slow enough so that the subject's ability to predict the motion after the force switch overshadows any inability to extrapolate the present movement over his reaction time. While this assumption seems appropriate for the speed of this system it may not be a reasonable assumption for faster systems. A third assumption is that any error in the subject's estimate of the state of the system is small enough to be neglected. There may be some indication that under certain circumstances these errors should not be ignored. For example, in the present study the optimal switch point for the outer most orbit considered was the state of zero velocity and extreme positon (-4.445 cm). In interviews following the experiment subjects often indicated that their strategy for the "long oscillations", i.e. the outer most orbit, was to switch the force "right when it turned around". However, the average switch points for that orbit were late for both groups. This finding suggests that there may be some difficulty in perceiving a zero instantaneous velocity state that is preceeded by a high deceleration rate. In any case, such effects would be expected to effect both groups and therfore should not bias the comparison between groups.

There are two primary findings of the analysis described in the previous section. First, the pictorial display of the pendulum did not significantly aid the operator in achieving a a low session score. Secondly, it was found that the pictorial display did effect the behavioral chatacteristics and learning process of the operator. Those subjects given the pendulum display appeared to recognize the oscillatory characteristics of the system earlier. However, the manner in which their internal representations of the system changed with practice was significantly different between individual subjects. This suggests the pendulum display not only aided the subject in forming his/her initial internal model of the system, but that it also caused significant differences in the way different subjects learned the task. This second finding may mean that the pendulum display permitted the operator to use a pre-existing internal model of the pendulum dynamics improving the operator's understanding of the system dynamics initially. Although these subjects demonstated more veridical initial interpretations of the dynamics their task scores did not show an improvement over the dot subjects. Those subjects given the abstract display of the system began with highly non-veridical internal models of the dynamics but with practice these models improved substantially.

The analysis performed on the type of model used to describe the operator's internal representation has several possible implications. The probability that a subject would be modelled by the more veridical type of model (Type II model) was significantly higher for the pendulum group on the first day of practice. This suggests that the pictorial display did aid the subjects initially in interpreting this oscillatory characteristic of the system. The majority of subjects with the abstract display did not exhibit this type of behavior until later in practice. However, once the subjects entered this category of performance the abstract display subjects showed significant improvement in the B1 parameter indicating that their improvement in performance from this point was directly related to the springlike or oscillatory system characteristics.

This analysis demonstrates the importance of the role of the non-verdical internal human model in evaluating the human operator in dynamic systems. Overall performance behavior does not give information concerning the internal structure of the human's interpretation of the system he is controlling. While improvement in performance can be detected, the characteristics of that improvement are not at all evident from gross overall performance measures. In this case, while the subjects from both groups were generating similar performance measures the type of behavior generating these performance measures was characteristically different. The internal model concept allows the analysis of some of these changes that occur in the human operator's internal representation of the system over practice. In the present experiment this concept is used to characterize the differences in learning behavior for subjects seeing different displays.

Kieras and Bovair (1983) demonstated in their study that a mental model, or so called "device" model, can aid performance if the model explains the mechanisms that are involved in fulfilling the operator's goals. They contend that if the model does not provide information explaining how or why the operator is to achieve a goal then it is not useful.

In their experiments they attempted to empirically assure that the all the subjects had approximately the same internal or "device" model prior to beginning the experiments. This was done by instructing the subjects on the model and testing them on their knowledge of the information povided to them. In the present experiments subjects were given no special training relevant to the dynamics of a pendulum. The subject was allowed to use the existing model he/she had for the physical entity of a pendulum. There is no evidence that this representation is the same for each subject. In fact the results of this study, among others (Larkin, 1983), indicate that these internal representations vary significantly from operator to operator. This suggests the extent to which the pendulum display aided the operator may have been dependent upon the nature of his/her existing model of a pendulum and whether that representation could provide the operator with information relevant to the goal of the task.

The significant differences between the two groups early in practice suggest that the pendulum subjects were using their internal representations of a pendulum. However, there is no indication that this pendulum "device" model provided the subjects with sufficiently relevant goal-seeking information to substantially improve their performance of the task. This suggests that while the pendulum display did provide the operator with relevant information concerning the oscillatory characteristics of the system, the subjects, in general, were not able to extract the information neccessary to achieve a low score.

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