

COMPARISON OF THE EFFECTIVE TIME CONSTANT
WITH OTHER METHODS OF VARYING TASK DIFFICULTY
IN ADAPTIVE TRAINING.

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In general, adaptive training can be thought of as the adjustment of training task difficulty in accordance with the measured level of trainee skill with the goal of bringing his skill to some specified level. The individual trainee progresses efficiently at his own rate to the criterion level of performance. Conceptually, and from the results of empirical investigations to date, the adaptive training technique holds promise of being a significant advance in training technology. This report summarizes the progress to date of an experiment designed to compare the training and transfer of training effects of different adaptive variables in the adaptive training context. It also compares the adaptive technique to a more conventional training method.

In the practical application of the adaptive training techniques a number of decisions must be made. One of these decisions is that of the choice of the parameter in the training system to be adjusted in order to increase or decrease task difficulty. This parameter has been termed the adaptive variable.

In a very real sense almost any learning situation is adaptive. Usually, the learner or his instructor has some goal in mind which is more or less well defined. The learner moves through the learning process toward the goal in steps graded as to difficulty either by the instructor or set by the curriculum. His advancement from one step to another is predicated, however grossly, on his accomplishment during the preceding step.

Normally, in those adaptive situations in which the levels of difficulty are set in steps and determined by the curriculum, there is resistance to relaxing the task and making it easier or doubling back so to speak. Rather the learner may simply stay with the given level of difficulty, spending time upon it until he has mastered it, before moving on to the next step.

An interesting example of more flexibility being introduced into this type of adaptive learning situation is that introduced not long ago into the training curricula for primary Army helicopter training students at Ft. Wolters, Texas. In this program a student having reached the level of the curriculum which he finds too difficult to master in the allotted time is set back, not a whole class but rather to the point within the following class at which his level of skill allows him to take up and continue. This type of adaptive training we, at one time, called "normo-adaptive." Here the larger aspects of the task, e.g., maneuvers in flying training, are sequenced as to difficulty, the student's performance is graded in systematic fashion and he advances or is

set back based upon his demonstrated accomplishment. This type of adaptive training can be made more objective, systematic and automated leaving the instructor to perform in a more managerial role than is the case in most training situations today.

A second type of adaptive training which lies perhaps on the other end of the continuum from normo-adaptive is that in which the trainee is attaining skill in some basic psychomotor task and the training apparatus adjusts automatically to increase in difficulty as the trainee becomes more skilled. This type of adaptive training has been variously called self adjusting vehicle simulation (Kelley, 1962); machine adaptive training (Regan, 1968); or simply adaptive training since, up to this time at least, the term generally has been used in connection with continuously and automatically adjusting some parameter of the vehicle being operated. In this type of adaptive training limits are set within which the vehicle dimension of interest is to be controlled. Task difficulty is varied so that the trainee can keep the system within the limits by varying the difficulty of the task along some other task dimension.

For example, the trainee may be asked to maintain altitude within plus or minus 100 ft. of a standard. Turbulence imposed upon the system may be varied from zero to very high turbulence as a function of the skill of the trainee in maintaining altitude within the prescribed limits. The system automatically adjusts level of difficulty of the task through increasing or decreasing the turbulence imposed upon the system. So long as the trainee maintains control within the prescribed limits the turbulence continues to increase. Once he is unable to maintain control within the limits the turbulence decreases allowing him to again stay within the limits. Thus, the difficulty of the task is matched to the trainee's skill and is continually forcing him toward a higher and higher skill level.

It was this type of machine adaptive or machine adjustive training which was first suggested for implementation in training situations. Upon close examination of this concept, notably in the studies in connection with 2B24 trainer, the concept was expanded and its potential explored for dealing with greater chunks of the training task.

The study in which we are engaged and which I will describe in more detail is concerned with the machine adaptive situation in which the trainee is being trained in a closed-loop compensatory tracking task analogous to attitude control of aircraft. In this task difficulty may be varied through changing the value of three different adaptive variables. Before discussing these variables I would first like to cite what I believe to be the criteria for selection of an adaptive variable in this type of task.

- 1 It must be capable of being described and quantified. That is, it must be capable of being measured. It's description and quantification must be meaningful to and usable by the trainer design engineer.

2. It must be related to task difficulty. That is, changes in the adaptive variable must bring about changes in level of performance. For example, in the control task of piloting an aircraft, driving an automobile or steering a boat, changes in the adaptive variable will require a change in skill to maintain a given level of precision of control.
3. It must be capable of being varied in a systematic way. Although this seems obvious, in a practical situation, it may not be easy to do.
4. When used in devices for training for transfer to a different system, it should not inhibit or interfere with transfer of training. Parenthetically, the addition of the adaptive training feature to a training task which has no training value in and of itself cannot be expected, magically, to endow that task with positive transfer characteristics.
5. It must be capable of being adjusted over a range commensurate with the trainee's skill both in increasing and decreasing difficulty. For example, the use of turbulence as an adaptive variable might be limited in its application because in some systems, of which the helicopter may be an example, the task difficulty for the beginning student must be reduced to some level below that of normal operation in calm air. That is, for the beginner, the task may need to be made easier than it actually is in the real system for most efficient training.
6. If possible, it must be realistic in the sense that it varies in ways in which the real task varies so that it is acceptable to the trainee. That is to say that it must not change the basic task so that it becomes strange and unreal to the trainee and not acceptable to him as a training situation.

What are some suitable adaptive variables? More specifically, for the training situation in which we are interested, what dimensions are most suited for variation to produce changes in the difficulty of task in which the trainee is learning to control the spatial movement of a vehicle such as an air or sea craft or an automobile.

Variations in the task which have been proposed for changing task difficulty have been such dimensions as:

1. Changes in control order (Hudson, 1964).
2. Changes in amount of display quickening (Birmingham, et al, 1962).

3. Changes in amount of aiding (Kelley, 1968).
4. Changes in forcing function level (Kelley, 1968).
5. Changes in effective time constant of the vehicle response (Matheny & Norman, 1968).

The adaptive variables to be investigated in the study in which we are engaged were selected following ground rules extracted from the criteria mentioned earlier. These rules were as follows: (1) the task required of the trainee must be a reasonable analog of a real world training task, (2) the task configuration must be simple enough to permit an analytical manipulation, (3) the variables must be stated in language which has meaning for those charged with the responsibility for implementing training concepts into training hardware, and (4) the variables must be stated explicitly and be capable of being quantified so as to establish empirical relationships between their variation and trainee performance.

The variables which we chose originally for study in the machine adaptive training situation were those of: (1) the effective time constant (t_e) or, more precisely, the gain-effective time constant product, (2) the external forcing function or analogously the amount of turbulence acting on the system, and (3) system quickening. These variables were chosen because they were thought to meet the criteria enumerated above. However, the third variable, quickening, has given us a good deal of difficulty in its definition and implementation. This problem will be discussed in connection with the description of the variables to follow.

The first variable, the effective time constant, (t_e) is a construct which can be described operationally and explicitly from measurable aspects of the vehicles response dynamics. It is a measure of the speed with which the operator sees the results of a control movement when operating the vehicle. It can be shown to be a function of the gain (K), natural frequency (ω), and damping (ζ) of the machine which the operator is controlling and of the operator's perceptual threshold, i.e., the level to which the output of the machine must rise before it can be detected by the operator. These parameters may be combined into an effective time constant (t_e) for the man-machine system. The value of the effective time constant was shown to be related to level of precision of control while individually the parameters going to make it up were not (Matheny and Norman, 1968). In the practical implementation of this construct within a training device those coefficients and values of the vehicles equations which affect its speed of response to a control input can be used to manipulate the time response of the system, i.e., the effective time constant of the system.

In implementing the effective time constant as an adaptive variable the results of earlier experiments (Matheny and Norman, 1968) were used as a

guide. Those experiments showed t_e to be related to final level of precision of control and to rate of learning. It was also found that level of performance was related to the interactive effect of t_e and system gain (K) as expressed by the product of the two (Kt_e). The effect of gain was particularly evident during the early training trials with the effect decreasing as learning progressed.

In their report Matheny and Norman suggested that, since gain was important in the early training trials with t_e becoming more important in determining final level of performance, these two variables might profitably be used in studies of adaptive training in the following way. In the beginning of training an optimum gain and t_e would be provided. Based upon student performance gain would then be varied to provide a more difficult task followed by variations in the t_e to make it progressively more difficult.

An external forcing function, e.g., turbulence, as an adaptive variable is relatively straightforward in its definition. However, in defining it operationally one must make decisions about what characteristics of the turbulence spectrum will be varied. Thus, decisions must be made as to whether to vary frequency, amplitude or both of the forcing function signature in affecting task difficulty. Most importantly the bandwidth of the forcing function would seem to be critical in that it may interact with both the rate of increase or decrease in difficulty and the length of the interval over which performance is measured and upon which changes in difficulty are based.

However, an external forcing function such as turbulence lends itself for use as an adaptive variable in the adaptive training situation and has been investigated in this regard by Lowes et al (1967). As indicated earlier, a consideration in its use is that in systems which are fundamentally difficult to control because of their system dynamics, level of difficulty cannot be decreased below the level set by the system dynamics. Thus, in the initial stages of training the use of turbulence as an adaptive variable may not be as appropriate as the use of some other or will require its being used in conjunction with some other variable.

The variable of system quickening has taken the most time to sort out and to implement as an adaptive variable. This is due to a number of differences between what various experimenters have actually changed within systems when they have reported them as being quickened or aided.

In our original thinking about quickening and aiding as adaptive variables, aiding appeared to be most useful in performing a positioning task in which a constant velocity is the required output and when the forcing function is relatively low frequency (Morgan, Cook, Chapanis and Lund, 1963). However, we found that the efficacy of aiding has been seriously questioned even in this application (Simon and Smith, 1956). Further, a characteristic of aiding is that the operator must make more control movements to obtain a simple output than he would in unaided tracking (Morgan et al., 1963).

With quickening, on the other hand, the operator's display shows what he should do with his control. Moreover, quickening appears most useful when a system containing integrations, such as an aircraft or submarine, must be operated (Morgan, et al, 1963). In fact, Sweeney, Bailey and Dowd, (1957) showed that control of ground speed in a simulated hovering helicopter can be substantially improved through the use of quickening. In addition, Holland and Henson (1956) have demonstrated positive transfer between quickened and unquickened systems.

Thus, quickening appeared to be highly suitable as an adaptive variable except that special displays are normally required. That is, conventionally, a special, quickened display is used which does not show the actual state of the system. Additional displays are required to provide this information (McCormick, 1964). Further, it was noted that in much of the research on quickening, little attention had been paid to this point and error scores were derived not for the system output but for the displayed error (Birmingham, Chernikoff, and Ziegler, 1962; Holland and Henson, 1956; and Birmingham, Kahn and Taylor, 1954, for example). Thus, it may be concluded that two types of quickening have actually been studied; display quickening and system quickening in which the actual output of the system is changed by quickening. For system quickening, no special or supplementary displays would be required.

At the present time we are both operationally defining what system changes are to occur with so-called quickening or aiding and examining the result in the light of the criteria set forth earlier for an adaptive variable. It may well be that the quickening and aiding concepts are ones which should be given a relatively low priority when considering candidates for adaptive variables.

The experimental plan is to train subjects under three adaptive training conditions and to transfer the subjects, after training, to a common criterion task. Also, the adaptive training technique is to be compared with more conventional methods of training.

Two criterion tasks are required. One task, termed the operational task, represents the actual system to which transfer is to take place. The second criterion task represents the training task from which transfer to the operational task is made. These two tasks represent the operational system and the operational system trainer of the actual training situation.

The necessity for both a training task and an operational task is due to the fact that two problems are seen as necessary of being investigated. The first of these concerns the efficacy of the adaptive training technique for training to criteria in a given task and the comparison of different methods of varying the difficulty level of the task. The second problem concerns the effect upon transfer of training. That is, will differential transfer of

training take place as a function of the method of training in the training task, i.e., adaptive or conventional, and also will differential amounts of transfer occur as a function of the adaptive variable used in the adaptive training task?

Therefore, a criterion task was set up whose response dynamics were representative of a high speed jet aircraft to which the trainee would transfer after reaching criterion on the training task. The training task was configured to embody different response dynamics from the criterion task but with its gain time constant product the same as for the operational task.

During adaptive training the level of task difficulty varies in accordance with the trainee's level of skill until he has reached criterion performance and the adaptive variable has reached a value equal to that of the criterion training task. In the method of conventional training the variation in task difficulty is under the direction of an "instructor." The method may be considered to be essentially adaptive although not automatically or continuously so. Under this method, the trainee's practice is started under conditions in which the task is the least difficult. Upon his attaining the criterion level of proficiency under this level of difficulty the instructor "steps" the difficulty variable up to the next higher level. This progression continues until the trainee performs to criterion proficiency under the criterion level of difficulty. Five "steps" of difficulty are incorporated into this technique of training.

As mentioned earlier there are a number of questions to which answers are needed when an adaptive variable is to be introduced into a training device. Of prime importance is a means of measuring trainee performance which is sensitive to changes in his skill level and relevant to the task being accomplished. In our experiment we are using the integrated absolute error as the measure of trainee performance. This measure has been shown in the past (Demaree, et al., 1965) to be suitable for this type of task.

Another major problem is that of setting the rate at which the difficulty of the task should be increased or decreased as the measured level of trainee performance increases or decreases. We have no general solution to this problem and can only try to optimize it for our own experiment through pre-testing. This is a problem which requires serious and systematic investigation before we can get the most from adaptive training.

There is yet another major problem which we had to face squarely in carrying out the experiment. This is the problem of specifying the amount of change in difficulty per unit change in the physical measure of the adaptive variable. Or, conversely, what amount of change in the adaptive variable will bring about a unit change in difficulty? This is a problem which must be faced by those who attempt to build adaptive variables into training devices

and who wish to generalize the findings from studies using a given adaptive variable to what might happen with a different adaptive variable. For example, supposing that studies determine the rate at which difficulty should be increased or decreased with forcing function as the adaptive variable. To use what we have learned about the rate of change of this adaptive variable when considering another we need to know something about the relative difficulty of the two. For each adaptive variable which we consider we need to know how much change in it is required to bring about a unit change in difficulty. A unit increase in one variable may be equivalent in terms of its effect upon trainee performance to a three unit increase in another. These ratios must be established empirically before useful comparisons of different ways of changing difficulty level can be made.

Since this particular problem has not been given attention in the literature and those who attempt to introduce adaptive training techniques into training devices will be faced with it, I will describe a method which we have come up with which we believe is at least one general solution to the problem.

In this method data collection is carried out from which learning curves for each of several levels of each of the adaptive variables may be plotted. By way of illustration, four groups of subjects are trained on four different levels of an adaptive variable such as external forcing function to determine the rate of learning and final level of performance under each. These data are used to establish the relationship between levels of forcing function and level of difficulty. Similarly, four groups are trained at four levels of effective time constant and the data used to establish the relationship between level of t_e and difficulty. From such data the amount of change in the adaptive variable necessary to bring about a unit change in difficulty can be established and ratios between them can be determined.

Hypothetical data from such experiments and how they would be used to establish ratios are shown in figure 1 and 2 for illustrative purposes. Figure 1 illustrates the learning curves for four groups of subjects each trained under a different level of forcing function. The midpoint of each curve is then taken as a measure of the relationship between level of the adaptive variable and difficulty (as defined by the amount of error) and plotted as shown in figure 2. In figure 2 the midpoints of learning curves in which different values of t_e were used is also plotted. The t_e data are collected in the same manner as was the midpoint data for the forcing function.

Figure 2 provides the information for determining the ratio between the two adaptive variables necessary to bring about equivalent changes in difficulty. In figure 2 the unit change in error, A , is brought about by a 1 unit change in t_e and a 2 unit change in forcing function.

In this illustration level of difficulty is equated to error. As an alternate method, difficulty may also be measured by the amount of practice

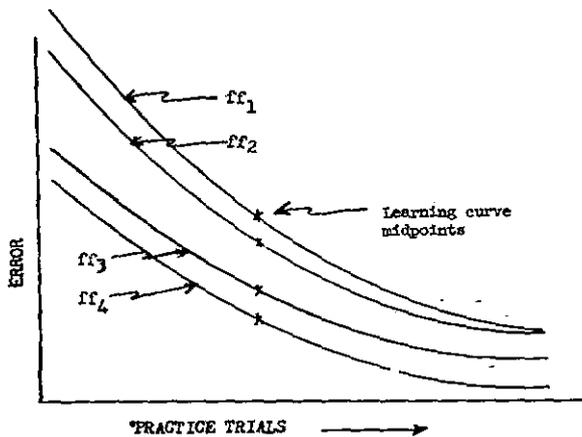


Figure 1. Learning Curves for Four Levels of Forcing Function (ff)

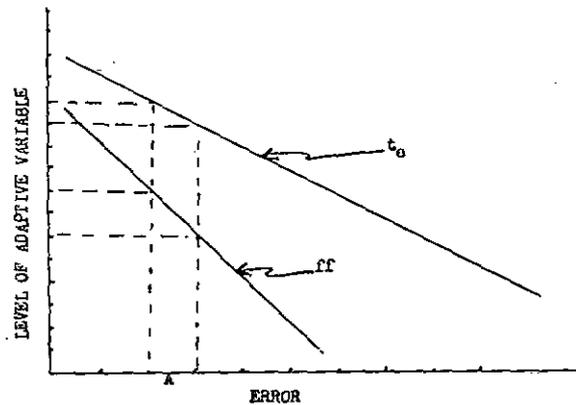


Figure 2. Plot of the Midpoint Values of Learning Curves as Obtained in Figure 1 for the Two Variables of Forcing Function (ff) and Effective Time Constant (t_e)

or amount of time necessary to attain a prescribed level of proficiency given discreet levels of the adaptive variable. Difficulty ratios between variables may then be established based upon these "time to criteria" values.

In summary, we are carrying out an experiment in which three different adaptive variables are being compared, both as to their effect upon learning the training task and upon transfer to a criterion task. In addition, the adaptive technique is being compared to the more conventional technique of advancing the student after he has acquired a prescribed level of skill.

In carrying out this experiment we have encountered many of the problems and the unknowns which one would face were he to attempt to introduce adaptive training into a training device at this time. The problems of performance measurement, rate of increase or decrease of difficulty, performance scoring interval, and equating of difficulty between adaptive variables are some of the major ones. We have the feeling that we are trying to solve n equations with m unknowns. But the concept is too promising not to dig in and begin collecting the data and knowledge which will allow us to use it effectively in our training devices.

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