THE EVALUATION AND CONTROL OF HUMAN SKILL

By B.R.Gaines

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Abstract The system under investigation consists of a human operator coupled to a process with variable parameters. An auxiliary control loop regulates these parameters according to some measure of the state of the operator. Experiments so far have been mainly concerned with varying the difficulty of a control task so as to maintain the operator's mean error constant, and it has been demonstrated that it is possible to make a rapid and meaningful evaluation of the operator's ability to perform the task in terms of the assymptotic level of difficulty reached. A two-parameter automated tester is described which sweeps out trajectories of equal difficulty in the natural-frequency/damping-ratio plane. Future experiments will evaluate the possible uses of these techniques in teaching machines for perceptual-motor skills.

The work described is taking place at the Cambridge University Psychological Laboratory, Downing St., Cambridge, under a contract from the Ministry of Defence.

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Introduction The problems of selecting and training operators to perform skilled tasks are recognized as ones of particular importance to military establishments, airlines etc., but are not restricted to these. In an educational context it has been demonstrated that verbal tests may be negative predictors of scientific and technical ability, and that spatial tests, not normally administered, are of high validity (Macfarlane Smith 1964). Thus rapid evaluation of tracking ability which has a high spatial loading (Fleishman 1963) could be useful in selection for technician grades as well as its more obvious application in selecting drivers and pilots. In a social and industrial context there is a need for fluidity of manpower involving accurate selection and re-training. In a medical context the evaluation of brain-damage suffers from lack of quantitative measures of motor ability, and the industrial rehabilitation of the mentally sick or physically disabled has hardly been investigated although it could have important economic consequences (Gedye 1965).

In this paper the problem of evaluation and control of human skill is treated as one of automation. It is the essence of perceptual-motor skills that they are non-verbal and externally paced by the controlled system (Gaines 1965). Both these factors weigh heaviliy against human intervention in the learning process, and conventional training consists largely of example and partialling the task. The lack of verbalization in skills makes impossible the introspective analysis which is fundamental to the good teaching of cognitive skills, and the parallel of the human teacher is the automatic adaptive controller or learning machine rather than the human controller. This is not to propose that trainers for perceptual-motor skills must necessarily be complex machines, but rather the reverse - that simplicity will be achieved through the use of a control-theoretic approach to what is essentially a control problem. Present-day simulators have a complexity which exceeds that of automated training devices which may be added to them.

The system to be considered in this paper is shown in Diagram (1). The human operator is coupled to a variable process by means of a (visual) display and a (manual) control. The parameters of the process are determined by

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an auxiliary computer on the basis of information about the operator's performance or his state. In a testing situation the computer might adjust the process parameters until the operator's performance deteriorates or improves to a prescribed level, and then, maintaining this level, sweep out parameter trajectories of equal difficulty. In a training situation the computer might adjust the parameters to maintain performance in a region where the operator's rate of learning is maximal, converging meanwhile to the process condition for which training is required. This type of system is formally equivalent to a 'teaching-machine' for a cognitive skill, and work on other uses of teaching-machines such as guidance (Newman 1964) or on more complex 'adaptive' machines (Smallwood 1962) carries over directly to automated trainers.

Previous Work on Automated Trainers Compared with work on teaching-machines for cognitive skills, however, there has been remarkably little developement of similar devices for perceptual-motor skills. Pask (1961) built and tested a machine for training operators of card-punches in which cueing, rate of presentation and difficulty of items were varied as a function of speed and accuracy of response; eight years ago Stockbridge and Siddall (1956) suggested the use of a guided-weapons trainer in which 'the difficulty of the task is proprtional to the success of the subject'; more recently Ziegler, Birmingham and Chernikoff (1962) have described 'a teaching-machine for the selection of operators of higher order vehicles', which removes 'quickening' as the subject's mean error modulus decreases; Kelley (1962) has reported similar work with the General Vehicular Trainer; and Hudson has conducted an extensive series of tests with this type of apparatus(Hudson 1964).

Only Hudson's experiments are sufficiently large and complete to permit reliable interpretation. In his apparatus the gain, stability and quickening of a two-dimensional, third-order system could be varied as parameters of difficulty. The technique for doing this automatically according to the operator's mean error was unsatisfactory, and his main results depend on trials in which the experimenter manually adjusted a given parameter to maintain the operator's performance at a fixed level (measured by the number of "out of controls" when the controlled spot went off the edge of the display). He trained 73 subjects for 10 hours each under varying conditions including operating on a pure third-order system throughout. His main result is that the plot of test performance on a third-order system after 10 hours training against the level of difficulty during training is strongly U-shaped, with both the easy-training and the difficult-training groups being worse than those who trained at a moderate level of difficulty. Hudson also finds that, although as previously reported (Parker 1959) the initial performance on criterion or partial tasks is a poor predictor of the final test performance ($\rho < .6$),

the level reached on the first runs under feedback conditions is a very good predictor of final performance ($\rho > .9$). Since the apparatus was such as to heavily penalize an operator who went out of control (resetting took five seconds) Hudson's results cannot readily be generalized, but they suggest that maintaining a moderate level of difficulty for the operator is a good training strategy, and that the level where performance deteriorates is a better predictor of final performance than any fixed test.

Present Work on Automated Trainers The work on feedback trainers at Cambridge is designed to extend that described above in several directions. These include the investigation of more realistic training situations in which a tracking task is only part of the skill; the developement of tests in which more than one dimension of ability is measured by sweeping out trajectories of equal difficulty in a multi-parameter task; the use of a criterion of constant difficulty relative to the operator rather than one of variable absolute difficulty according to his performance; examination of the outer loop controlling difficulty to establish its behaviour and stability; and the use of control-groups who have the same variation of parameters as are generated by the group undergoing feedback training to establish the extent to which the feedback is responsible for better training.

The two-parameter feedback tester/trainer in use at present is shown in Diagram (2). The transfer function of the simulated craft is similar to that used by Hall (1963) in his investigation of linear models of the human pilot. It represents a third-order system made up of an integrator in cascade with a second-order system whose undamped natural frequency and damping-ratio form the parameters of difficulty. As the former decreases to zero the system becomes more sluggish and anticipation is required. As the latter goes zero or negative the system becomes jittery and a rapid, smooth mode of control is essential. It has been convenient in most of our studies to vary one or the other of these parameters, but any linear trajectory in the f_n/J plane is readily set up. The tape-recorder allows parameter trajectories generated by one operator to be used with another.

The difficulty of the task is increased if the error is less than a given level and decreased if it is more. This is realized by subtracting an offset from the modulus of the error and feeding this through an integrator to the servo determining the craft parameters. The servo naturally has some 'noise' on its output due to local variation of the error signal, but this is negligible and the only major movements are due to variations in performance. Typical regulation of difficulty with time is shown in Diagram (4) and the rise to an assymptotic level can clearly be seen. A and B were generated by a trained operator under different conditions. C was generated by an operator with no training but the same ability, and it may be seen that the rate of rise is less reflecting the extent of training.

The range of peak levels of difficulty attained by a normal population may be seen in Diagram (3) which shows the initial runs with variable natural frequency. In an experiment with RAF pilots this parameter was in a four to one ratio between the best and the worst operators, and its distribution was skewed relative to a normal population as would be expected if selection tests winnow out those with poor equalization ability. Significant and highly significant correlations were found between previous RAF flying test results and the present measures suggesting that common factors exist between the instructor's rating and equalization ability measured in this way.

When two parameters are to be varied so as to sweep out trajectories of equal difficulty one is regulated by the operator's performance and the other varies continuously or discretely with time. Discrete sweeps for three operators are shown in Diagram (5) and it may be seen, for example, that only C was able to control the craft at zero damping. These graphs are obviously related to stability diagrams for aircraft controllers and interpretation is possible on the basis of linear models of the human operator. For practical testing four sweeps of four minutes each allow several independent readings to be taken at points sufficient to define the graph.

To investigate the training potential of these devices a laboratory situation has been set up which corresponds a little more closely to reality than have those previously described, and in which appreciable learning takes place over short periods. The system shown in Diagram (2) is again used with the natural frequency fixed and the damping ratio going negative to increase difficulty. However instead of a joystick control the operator has a push button which when pressed gives the system a fixed impulse whose sign is determined by a counter. This is set to give a fixed repetetive sequence of positive or negative impulses, and thus the operator has to learn not only to press the button according to the display but also the sequence of impulse signs. Without the feedback trainer the task is extremely difficult since the it is necessary to control the system to learn the impulse sequence but also necessary to know the sequence if control of the right sign it to be applied. This interdependence mirrors reality and it will be interesting to compare learning under feedback training with that obtained by partialling the task and teaching the impulse sequence and method of control separately. One feels that the skill learnt by joint developement will be more robust than that learnt in stages, but the experimental comparison has not yet been made.

Conclusion Since virtually nothing is known of the adaptive strategy of the human operator the design of a feedback trainer cannot be treated at present as a problem in controller synthesis. However practical and theoretical

advances in our knowledge of human adaption and its identification will make this possible in the future. At present empirical studies of potential training/testing devices are necessary and these are being carried out on both real and simulated operators. The most useful criterion developed is to maintain the difficulty of the task constant for the operator by regulating its parameters to keep his mean error constant. Realization of this criterion in a simulator is both simple and viable, and parameters already available have been shown suitable for variation of difficulty.

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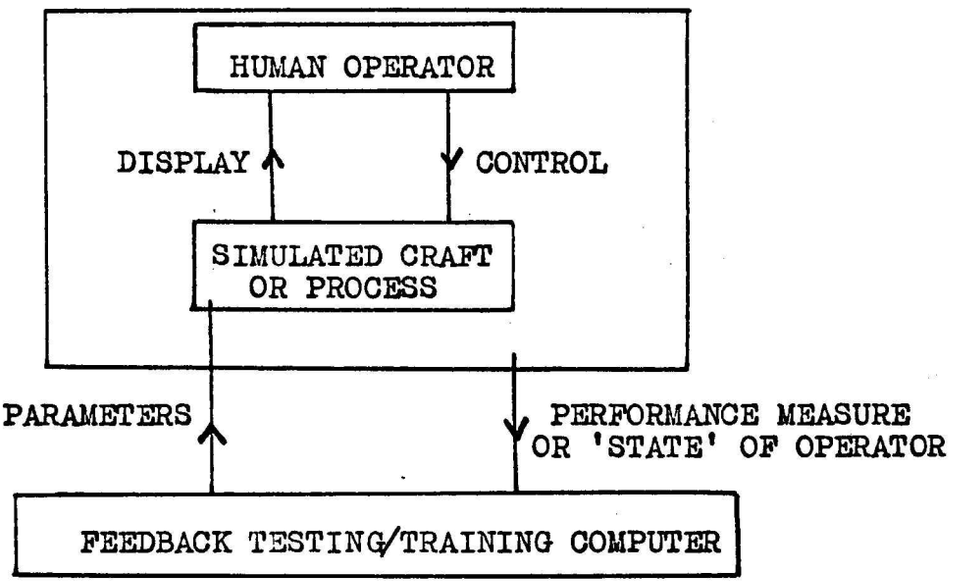


DIAGRAM (1)

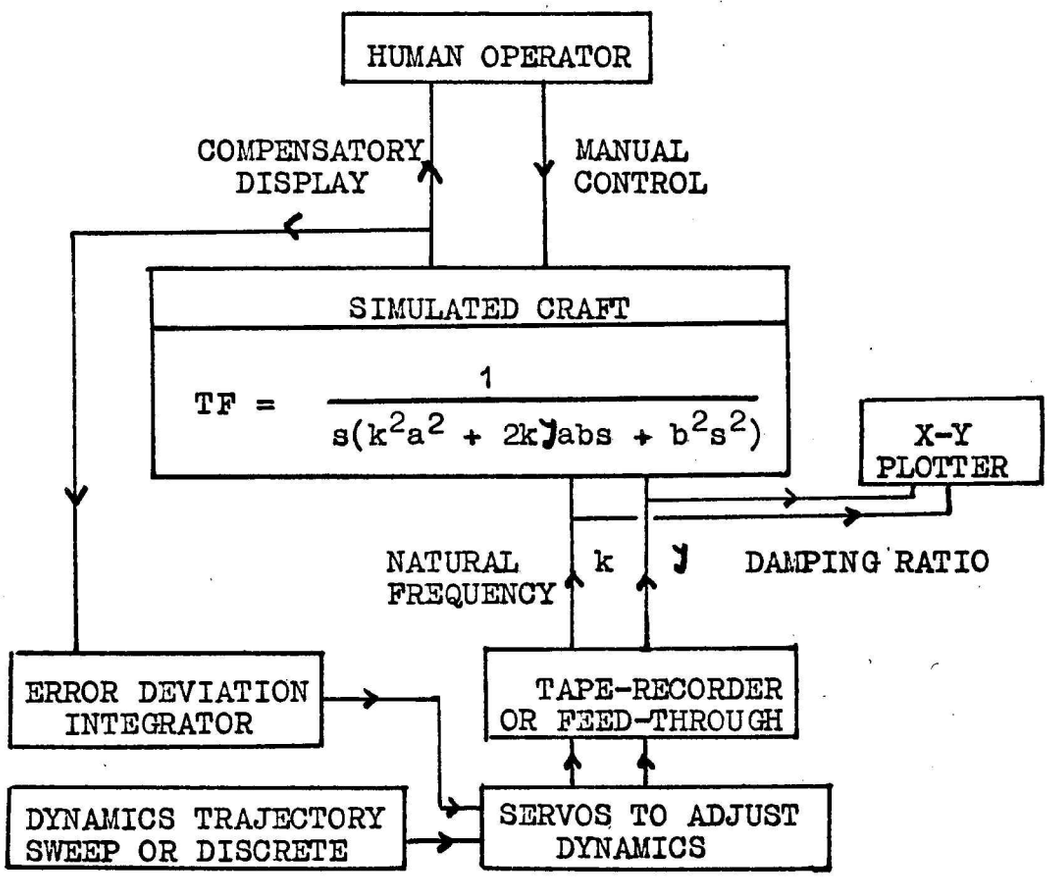
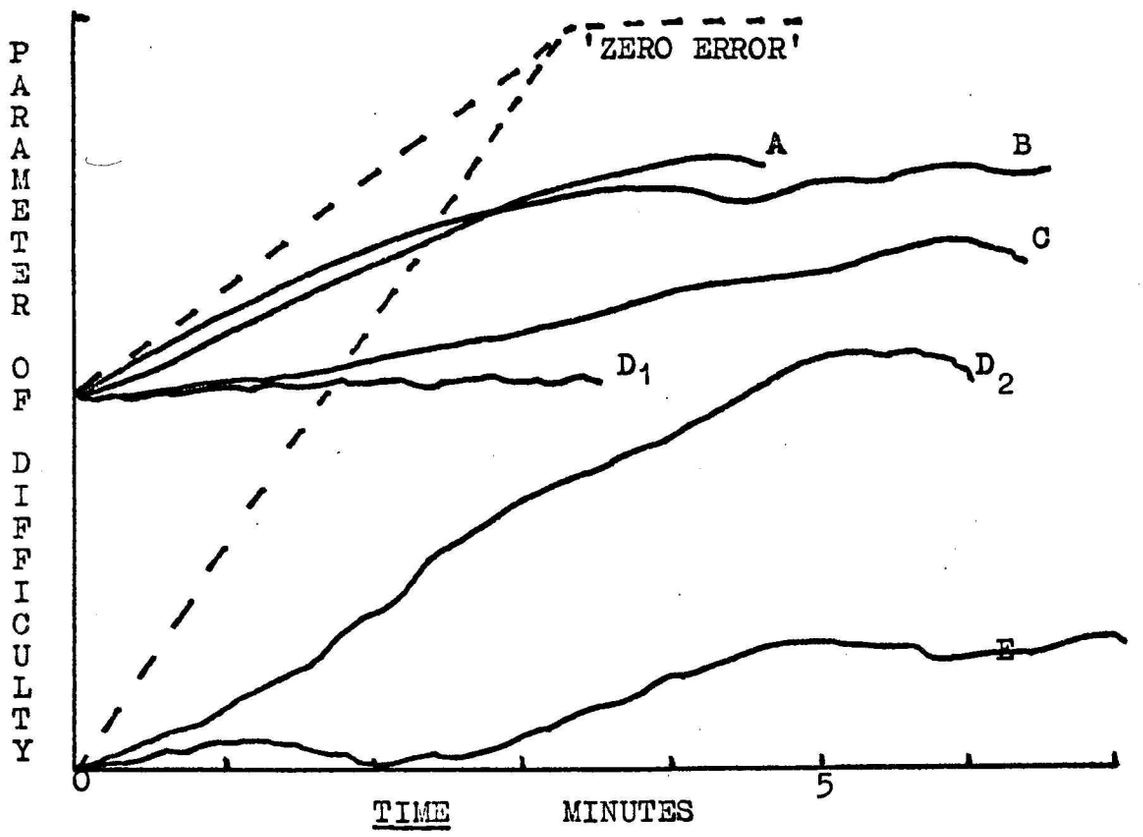


DIAGRAM (2)

DIAGRAM (3)



BEHAVIOUR OF FEEDBACK TESTER/TRAINER COUPLED TO OPERATORS

The plot shows the manner in which the difficulty (undamped natural frequency) of a control task is varied according to the ability of the operator.

The graphs, 'Zero Error' show the rate of increase of difficulty with a perfect operator who maintains zero error.

A human operator cannot achieve this performance, makes errors and above a certain level of difficulty becomes unstable.The machine regulates the parameters of the control task to keep the operator just below this level.

The graphs show various subjects being taken to the level at which their performance deteriorates to a prescribed level.

Comparison of operators A and B is interesting because B was experienced on the task but A had piloting experience. It will be seen that B has the faster initial rate of increase but is eventually surpassed by A.

With subject D commencing at the same level of difficulty as the others there was no increase, D_1. The initial level was therefore set down and it can be seen from D_2 that this subject was only just able to exceed the normal initial level.

Similarly the operator E could not attain this level.

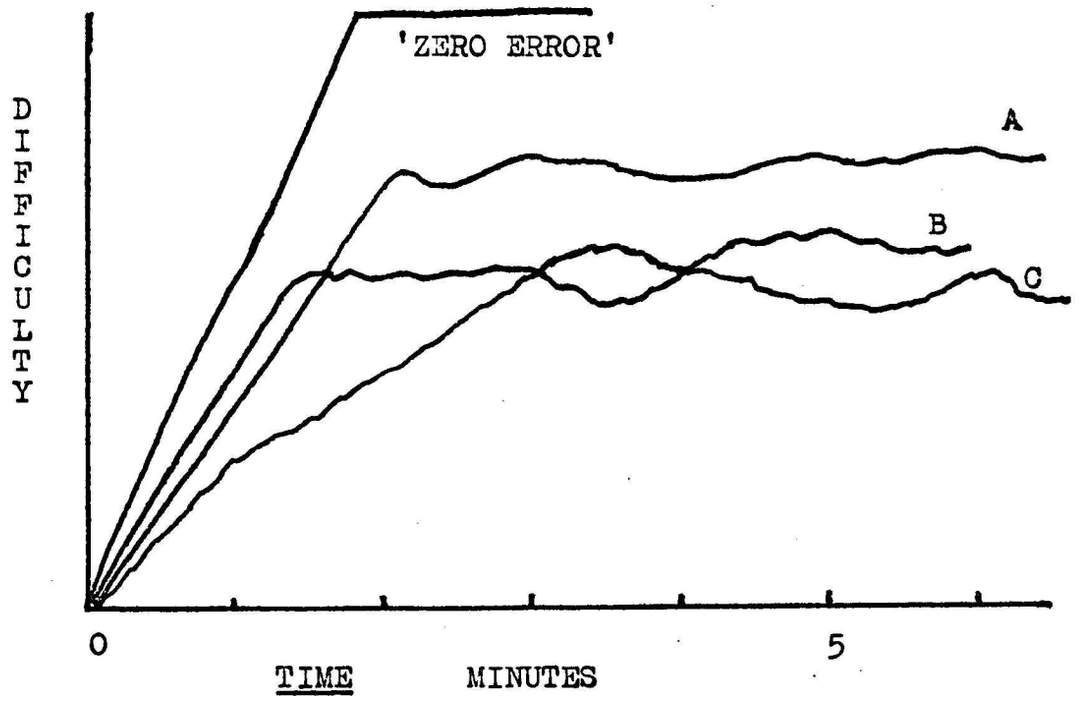


DIAGRAM (4)

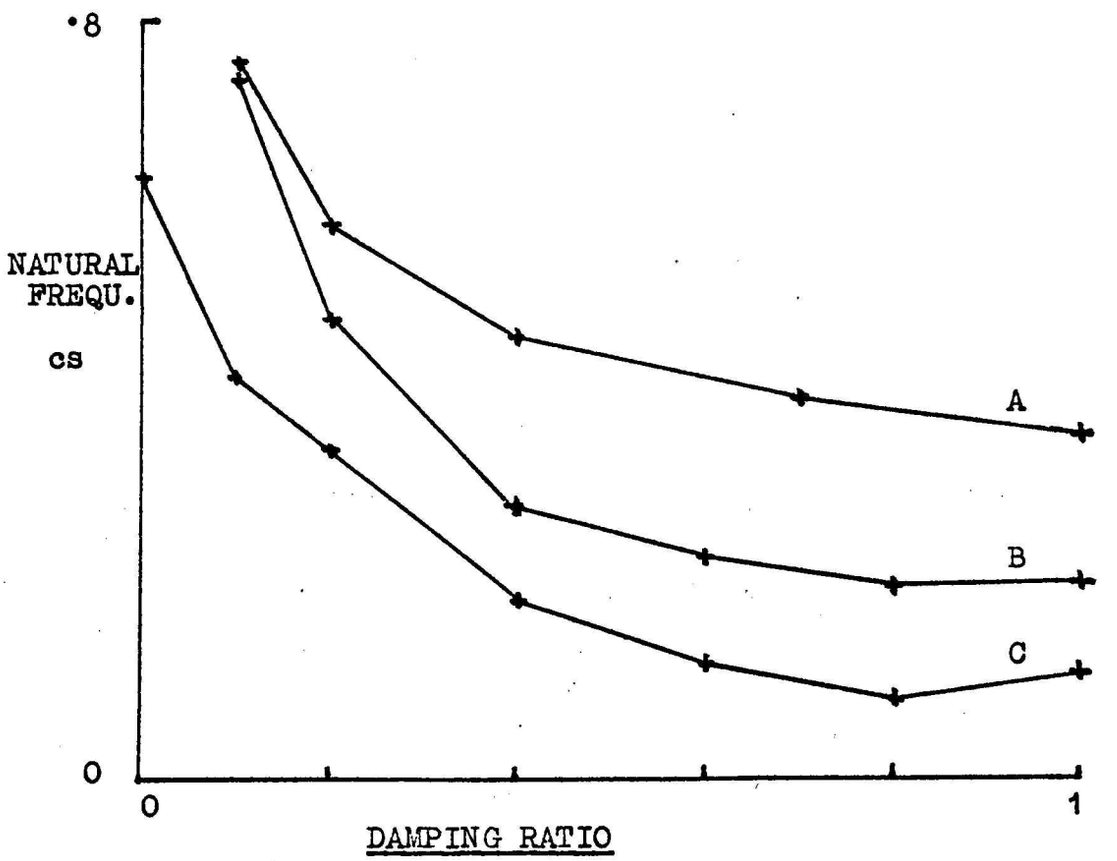


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