A TOUCH-DETECTING TEACHING MACHINE WITH AUDITORY REINFORCEMENT¹

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This teaching machine has been designed and used to train reading and other visual discrimination skills with normal and retarded children. On each frame the subject responds by touching one of three response panels on which are projected the multiple-choice alternatives. The response panels are coated with a transparent conducting film which allows electronic detection of this simple and direct response. Correct responses are reinforced by the machine naming the stimulus, while auditory reinforcement is absent for an incorrect response. The subject's performance level is continuously computed as an exponentially weighted moving average. The measure is weighted so that it rapidly follows recent changes in performance.

This experimental apparatus² has been used by the authors to test hypotheses on the operant training of reading and other visual discrimination skills in pre-school normal and older, severely sub-normal children. The results will be reported elsewhere.

The form of display presented to the subject is shown in Fig. 1. The normal cycle of operation is as follows: if the subject touches the lower response panel, which correctly relates to the upper stimulus panel, an auditory stimulus follows. This consists of the replaying of a pre-recorded item, naming the visual stimulus. The auditory stimulus is absent for an incorrect response. In either case, a new display appears after the duration of time allocated to the auditory item, and the system is ready to detect a new response. The operating cycle can be varied by using the program codings described below.

The apparatus is in some respects similar to that described by Hively (1964), but it differs

in important features such as electronic touch detection, auditory stimulus consequences, and the automatic computation of performance.

To simplify construction, the experimental apparatus uses commercially available sub-units where possible. The Sawyer's Rotomatic slide projector was selected from a number of otherwise similar machines because it accepts the Rototray magazine which holds 100 slides, thus enabling the machine to use recirculating programs. The Revox model G36 two-channel tape recorder replays the auditory stimuli, although subsequently a Fidelipac tape cartridge player has proved to be more convenient for this purpose. Both of these instruments can be operated remotely, which allows the control electronics to be connected to the instruments with the minimum of modification.

The slides are displayed on a back projection ground-glass screen. The front surface of the glass has three electrically conducting areas corresponding to the three picture panels of the multiple-choice test. The conducting areas and the associated electronics act as touch detectors for the subject's responses. A thin conducting layer of chromium is evaporated on the glass in these areas to an optical transmission of 60%, and thus only slightly reduces the brightness of the pictures.

A flow chart for the normal operating cycle of the apparatus is shown in Fig. 2. Given a response to a picture, the tape recorder ad-

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²The assistance of Mr. J. C. Pashley of Behavioural Research and Development Limited in the design and construction of this apparatus is gratefully acknowledged. A commercial version of the teaching machine suitable for research purposes is available from B. R. and D. Teaching Machines, 11 West View, Newcastle upon Tyne, NE12 0JL, England. The teaching machine, performance computer, and touch detector are the subjects of patent applications in Britain and U.S.A.

Fig. 1. General view of the subject's console showing the display.

vances one item, the loudspeaker being muted for an incorrect response. When a synchronizing pulse at the end of the recorded item is detected, the tape recorder is stopped and the

Fig. 2. Flow diagram of machine operating cycle.

slide projector advances one frame. This allows the stimulus slide to remain displayed during the auditory stimulus. The control electronics are reset as the new frame is presented to allow the next response to be detected.

Computation of Performance

The subject's performance level is continuously computed as an exponentially weighted moving average of response values where correct responses have a value of 1 and incorrect responses a value of 0. The operation of exponential smoothing gives a linear combination of the values of all the past responses. The weight given to previous response values decreases geometrically with the age of the response. Thus, with a smoothing constant of α , the current response value χ_n is given weight α and the previous responses are given weights $\alpha(1-\alpha)$, $\alpha(1-\alpha)^2$, $\alpha(1-\alpha)^3$, etc. The expression for the performance level therefore is

$$S_n(\chi) = \alpha\chi_n + \alpha(1-\alpha)\chi_{n-1} + \alpha(1-\alpha)^2\chi_{n-2} + \alpha(1-\alpha)^3\chi_{n-3} + \dots + \alpha(1-\alpha)^r\chi_{n-r} + \dots + \alpha(1-\alpha)^n\chi_1$$

It immediately follows that

$$S_n(\chi) = \alpha\chi_n + (1-\alpha)S_{n-1}(\chi)$$

The practical importance of this result is that only one value, the performance level at the previous response, needs to be stored. For a technical account of smoothing techniques see Brown (1963).

For a series of correct responses $S(\chi)$ tends to 1, and for a series of incorrect responses $S(\chi)$ tends to 0. Small values of α effectively give averaging over large numbers of responses and therefore the variance of $S(\chi)$ is small, whereas large values of α are desirable if rapid changes are expected in the probability of a correct response. Thus far, a value of $\alpha = 0.1$, which is equivalent to taking a moving average over 19 responses, has been selected because it offers a reasonable compromise between effective smoothing and excessive lag.

The results of a simulation of 1000 responses at chance level are shown in Fig. 3. Ninety-nine percent of the values of $S(\chi)$ fell below 0.58. Thus, a criterion of, say, $S(\chi) = 0.9$ may be taken as an indication that perform-

ance is above chance. It can be shown that when the probability of a correct response is 0.9, one standard deviation of $S(\chi)$ is 0.069, and thus the reliability of the performance measure at this point is fairly high. During two years of experimental work with the apparatus, this technique has provided a useful criterion for program change and could well be adapted for other learning experiments.

Fig. 3. Computer simulation of chance responding.

The simple analog circuit shown in Fig. 4 computes performance level. It is based on the controlled charge and discharge of a low leakage poly-carbonate film capacitor C1. For each response, the contact A should be arranged to close for 0.2 sec and VR2 should be set so that the capacitor discharges to 90% of its value before the response. For a correct response, contact B should be operated also for 0.2 sec, allowing a constant current to be drawn from the floating 75-v power supply. The value of this current should be set by adjustment of VR1 so that full-scale deflection is given by meter M1 when a long series of correct responses occurs. The precise duration of the contact closure is not critical, but it must be accurately maintained.

V1 operates as an electrometer, transforming the voltage on C1 into a current to drive the meter. The low grid current of V1 and the high insulation resistance of capacitor C1 allow time constants of the order of a day to be attained. In the experimental machine, indi-

cated performance level was found to decay by less than 1% per hour in the absence of new responses.

The cold cathode trigger tube V2 detects criterion level of performance which is set by adjustment of VR3. The contacts of RLA may be used to give a visual signal to the experimenter and to operate recording equipment.

Stimulus Presentation

The experimental apparatus was built as two units with an interconnecting cable. One unit, the subject's console, incorporates the visual stimulus display, projector, loudspeaker for auditory stimuli, and touch detector electronics.

The back projection screen is 9 in. square and displays the central 24 by 24 mm of the

Fig. 4. Circuit diagram of performance computer.

A—closed every response
B—closed for a correct response
C—close to set computer to zero
D—close to reset criterion indicator

C1—15 μ F
C2—1 μ F
C3—220pF

D1, D2—75 v zener, Mullard BZY94-C75
D3, D5, D6—Mullard OA202
D4—Mullard BYX10

R1—47K
R2—33K
R3—47K, 2W
R4—1K
R5—15M
R6—100K
R7—4.7M
R8—10K

RLA—miniature relay 120 v, 15K

M1—voltmeter 100 v fsd, 100 μ A movement

T1—100 v secondary
V1—6267
V2—Mullard Z700U

Fig. 5. A typical slide: 1—response dependent photo-cell codings. 2—this area is displayed on the screen. 3—correct alternative codings.

standard full frame 35-mm film format of 24 by 36 mm. This is shown in the diagram of a typical slide in Fig. 5. The remainder of the vertical format of the slide is allocated to optical codings of the correct alternative in the multiple choice picture test (C_a) and codings for response-dependent frame advance (R_a). The 6 mm below the displayed area of the slide is allocated to codings for C_{a1} , C_{a2} , and C_{a3} , the 6 mm above the display area being allocated to R_{a1} , R_{a2} , and R_{a3} . The convention adopted for the coding is:

white = 1 black = 0

$C_{an} = 1$: correct response for nth response panel

$C_{an} = 0$: incorrect response for nth response panel

$R_{dn} = 1$: touch detection allowed on nth response panel

$R_{dn} = 0$: touch detection inhibited on nth response panel

The R_a codings are used to reduce the number of alternatives.

The decoding is performed by selenium-based cadmium sulphide photoconductive cells mounted inside the Mirascreen above and below the ground-glass screen. This makes it unnecessary to provide an optically separate code reading system.

The Sawyer projector is used with a 75-mm lens. A modified version of the Sawyer Mira-

screen, which gives a folded optical path to the back projection screen, is used to keep the apparatus fairly compact. As originally manufactured, the Mirascreen required the projector to be placed in front of the unit. The bottom mirror was altered to allow the projector to be mounted at the rear of the unit to give the subject unrestricted access to the display. The original screen was replaced by a similar-sized screen having conducting areas for response detection.

Electronic Touch Detection

Each of the conducting areas on the front of the screen is connected to a high impedance electrical supply. The maximum current that can be drawn is $15\mu A$, which is less than the current commonly impressed for measurement of skin resistance (Venables and Martin, 1967) and so can be considered quite safe. When the conducting areas are touched, the leakage current which flows causes the potential to fall below its resting value of 150 v. This fall in potential is amplified by the high impedance ac-coupled amplifier shown in Fig. 6. The leading edge of the pulse fires the cold cathode trigger tube V2. The cathodes of the trigger tubes associated with each response panel are connected together so that once one has fired, the others are inhibited until the circuit has been reset after the display of the next frame. This ensures that the first response panel touched after frame advance is the only response to be detected.

Experimenter's Console

The experimenter's console, illustrated in Fig. 7, contains the tape recorder, control panel, and the remainder of the electronics. A meter displays the performance level, a monitor loudspeaker allows the experimenter to listen to the tape relay, and signal lamps indicate correct or incorrect response and performance reaching criterion level for program change. Push buttons are provided for manual operation of the apparatus. The twin-channel Revox tape recorder is used with a Philips CE.10 endless loop tape cassette and for this application the spool drive motors are disconnected from the main supply. The spoken items for auditory stimulus presentation are recorded on channel 1, with a synchronizing pulse on channel 2 between each recorded item. The frame advance pulse from the con-

Fig. 6. Circuit diagram of touch detector.

A—from touch panel

B—opened after a response is detected in order to reset
V2

C—connected to cathodes of V2 on other touch detectors

C1—0.01 μ F

C2—0.022 μ F

C3-220pF

DI—Mullard BYX10

D2—Mullard OA202

R1-1M

R2-22M

R3-22M

R4-100K

R5-100K

R6-1K

R7-3.3K

R8-1.5M

R9-1.5M

R10-4.7M

R11-10M

R12-4.7M

R13-47K

R14-10M

**RLA—miniature relay 120
v, 15K**

V1-12AX7

V2—Mullard Z700U

Fig. 7. The experimenter's console, showing monitor panel and Revox tape recorder fitted with endless loop tape.

lays slide change for the duration of the recorded item in the event of an incorrect response. When all the items have been recorded on the tape, the unused portion is removed from the loop so that both the slide magazine and the tape can recirculate without indicating the beginning or end of the program.

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control circuits starts the tape recorder and channel 1 replays the recorded item.

The student's console loudspeaker is connected only in the case of a correct response. When the synchronizing signal is replayed on channel 2, the control circuit stops the tape recorder and advances the slide projector one frame. This sequence has the advantage of retaining the display of the original stimulus material during the auditory stimulus, and de-