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Finite integer analysis of individual subject protocols during eyelid conditioning

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Theios (1972) has proposed that during classical eyelid conditioning the conditioned response protocols of "voluntary" responders (Vs) will require an additional stage, relative to "conditioned" responders (Cs), to be adequately described. In a test of this hypothesis, individual subject protocols from eyelid conditioning experiments using both classical and avoidance modes of reinforcement were subjected to finite integer analysis (Theios, 1968). During both modes of reinforcement, a two-state Markov model was found to provide an adequate description of most individual protocols for both Cs and Vs. In addition, there were no indications that Vs give predominantly C-form conditioned responses at the beginning of an experimental session and switch to predominantly V-form conditioned responses later in the session. Both of these results indicate that Theios' hypothesis is inaccurate at the level of the individual human subject.

Each subject in an eyelid conditioning experiment can be classified as giving predominantly C-form or predominantly V-form conditioned responses (CRs) using the objective Hartman-Ross (1961) response-slope criterion. The V-form CR is a relatively rapid, more complete eyelid closure of a longer duration than the C-form CR. Spence and Taylor (1951) originally separated subjects into "conditioners" (Cs) and "voluntaries" (Vs) because the V-form CR resembled an instrumental voluntary eyeblink and Spence and Taylor wished to separate out the data of potential voluntary responders from the data of "truly conditioned" responders.

In a recent theoretical paper, Theios (1972) provides a general hypothesis about eyelid conditioning with specific mathematical formulations based on the Spence-Taylor notion of C-V differences. Theios hypothesizes that all subjects begin an eyelid conditioning experiment in an unconditioned state with a low CR probability (P1) which remains constant for I trials. On trial I + 1, the subject enters a second response state during which he gives truly conditioned (i.e., C-form) responses and reaches a new asymptotic response rate, P2 (P2 > P1). On some trial J (J > I), those subjects classified as Vs enter still a third state of responsiveness during which they give instrumental voluntary (i.e., V-form) CRs and reach a still higher asymptotic response rate, P3. Theios provides both discrete and continuous mathematical versions of the increases in response rate up to asymptotes of P2 and P3 in the second and third states, respectively. All of these specific quantitative models hypothesize an additional state of responsiveness for Vs compared with Cs. In fact, Theios suggests that a subject may be identified as a C or a V by determining whether or not this third state of responsiveness is necessary to describe his CR protocol. In contrast, other recent empirical and theoretical papers dealing with eyelid conditioning suggest that the classification of a subject as C or V remains relatively stable throughout a conditioning session (e.g., Grant, 1972; Hellige, 1975; Hellige & Grant, 1974a b; Zajano & Grant, 1974; Zajano, Grant, & Schwartz, 1974). Therefore, it becomes important to evaluate Theios' hypothesis directly.

Finite integer analysis (Theios, 1968) of individual CR protocols provides a strong and direct test of the discrete-state mathematical formulation of Theios' (1972) hypothesis. Finite integer analysis allows likelihood ratio comparisons of 1, 2, 3, . . . n-state Markov models for each individual subject protocol, where maximum likelihood parameter estimates are used for each Markov model. The analysis indicates, for each subject, how many states of responsiveness are necessary to adequately describe the subject's protocol by using a series of chi-square likelihood ratio tests.[1] The discrete-state version of Theios' general hypothesis predicts that the response protocols from Cs should be adequately described by a two-state Markov model. However, the response protocols from Vs should require a third state of responsiveness, as determined by finite integer analysis. Furthermore, to the extent that a discrete-state model with a small number of states provides a reasonably good fit of typical eyelid conditioning response rates, finite integer analysis can provide a test of Theios' general hypothesis as well as

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the specific discrete-state version. Accordingly, individual subject data from recent eyelid conditioning experiments using both classical and avoidance modes of reinforcement were subjected to finite integer analysis.

METHOD

Apparatus

Details of the apparatus and general procedure are reported by Hellige and Grant (1974a, b), from whom the data to be analyzed were obtained.[2] The conditioned stimulus (CS) consisted of increasing the luminance of two 10-cm ground-glass disks from 1.5 mL (4.774 cd/m²) to 1.9 mL (6.047 cd/m²) for a duration of 700 msec. The unconditioned stimulus (UCS), when given, was a 200-msec 2 psi (13789.52 N/m²) airpuff directed to the corner of the subject's right eye. The CS-UCS interval was 500 msec, and the intertrial interval varied from 15 to 35 sec, with a mean of 25 sec. Any eyelid response of 1 mm or greater that occurred between 200 and 540 msec after CS onset was defined as a CR. During avoidance training, any CR occurring before UCS presentation caused the UCS to be omitted on that trial.

Procedure

All subjects were read neutral instructions asking them to neither aid nor inhibit their natural eyelid responses. Following these instructions, subjects in the classically conditioned groups received either 60 (CL 60) or 100 (CL 100) classically reinforced pairings of the CS and UCS. Subjects in the avoidance conditioned groups received either 60 (AV 60) or 100 (AV 100) trials of avoidance conditioning during which an appropriate CR caused the UCS to be omitted. In Group YK 100, each subject received a schedule of intermittent airpuff reinforcement that corresponded exactly to the intermittance generated by a subject in Group AV 100 (a yoked group).

Subjects

The subjects were 44 men and 68 women student volunteers from introductory psychology courses at the University of Wisconsin-Madison. The number of subjects in Groups CL 60, CL 100, AV 60, AV 100, and YK 100 was 20, 24, 20, 24, and 24, respectively.

RESULTS AND DISCUSSION

Each subject was classified as a C or a V using the Hartman-Ross (1961) response-slope criterion. There were 60 Cs and 52 Vs identified in this manner.

Results of Finite Integer Analysis

Finite integer analysis (Theios, 1968) was used to determine the maximum number of response states (one, two, three, or four) necessary to characterize adequately the response protocols of each individual subject.[3] Table 1 shows: (1) the mean negative natural logarithm of the maximum likelihoods (-LN LKHOOD) for models with one, two, three, or four response states and (2) mean likelihood ratio chi-square comparisons for models with 1 vs. 2, 2 vs. 3, and 3 vs. 4 response states. The means are shown for both Cs and Vs in all reinforcement contingency groups. Note that lower values of -LN LKHOOD indicate a better fit than higher values. In all cases, the difference in -LN LKHOOD between the one-state model and the two-state model are relatively large while differences between two-, three-, and four-state models are quite small. Likewise, for both Cs and Vs in every reinforcement contingency group the comparison between one- and two-state models produces a mean chi-square which exceeds the critical chi-square value with 2 df and $p < .05$. None of the other mean chi-squares exceeds the critical value even with $p < .10$. Furthermore, of the 112 individual protocols, 74 (38 Cs and 36 Vs) required two states while only nine (four Cs and five Vs) required three states. A total of 29 protocols (18 Cs and 11 Vs) required only a single state; that is, they showed no CR acquisition at all. No subject required as many as four response states. The most relevant finding for the primary hypothesis under investigation is that Vs did not require an extra response state as compared with Cs.

Table 1
Mean -LN Likelihoods* and Mean Chi-Square† Values for Cs and Vs in Each Reinforcement Group

	Number of States in Model				Mean Chi Squares		
	1	2	3	4	1 vs. 2	2 vs. 3	3 vs. 4
Cs							
CL 60	33.1	26.7	25.2	25.0	12.80	3.02	.40
CL 100	65.4	60.6	59.6	59.2	9.44	2.42	.70
AV 60	29.3	25.2	24.2	23.9	8.01	2.04	.58
AV 100	61.8	55.3	53.8	53.0	12.98	3.15	1.37
YK 100	57.4	54.4	53.5	53.4	6.00	1.77	.39
Vs							
CL 60	30.6	20.9	19.8	19.6	19.15	2.31	.51
CL 100	42.4	37.1	35.9	35.5	10.59	2.69	.65
AV 60	29.1	22.4	21.9	21.6	13.31	1.07	.54
AV 100	60.3	53.4	52.3	51.2	13.66	3.21	1.85
YK 100	51.4	44.2	42.9	42.7	14.43	2.45	.42

**–LN likelihood = natural log of the maximum likelihood. †Each pairwise chi square has 2 df (see Theios, 1968 and Note 1). Critical value for $p < .10$ is 4.61 (5.99 for $p < .05$).*

Prokasy (1972) presents the results of finite integer analysis of some classical eyelid conditioning data and reports that response protocol data from virtually all of his subjects were fit by a three-state model. This is consistent with the present analysis insofar as nothing was reported about Vs requiring an additional state relative to Cs. However, Prokasy's results are inconsistent with the present analysis which found a two-state model to be sufficient. Several differences in conditioning procedure may account for this inconsistency. For example, Prokasy used habituation trials, a much shorter intertrial interval than the present experiments, and analyzed 280 conditioning trials. Prokasy reports that the mean trial of transfer from State 2 to State 3 was about 100. Therefore, it might be argued that CR probability simply had not reached asymptote in the present experiments. While this seems reasonable in Groups CL 60 and AV 60, inspection of group data for Groups CL 100, AV 100, and YK 100 shows no increase in CR probability after about the 50th conditioning trial (see Figure 2 in Hellige & Grant, 1974b). Therefore, the difference between Prokasy's analysis and the present analysis suggests that it may be profitable to examine how the

number of required states, as determined by finite integer analysis, changes as a function of different classical conditioning procedures and number of trials.

It should be noted that in an analysis of Monte Carlo data, Prokasy (1972) demonstrates that finite integer analysis can indicate that three distinct states are sufficient for most subjects, even though the underlying process is continuous. Therefore, although the present analysis would suggest that there is merit in looking at CR probability changes as resulting from a discrete transition among a finite and small number of states (Theios, 1968), it should not be concluded that a more continuous model cannot also fit the data. However, this particular limitation of finite integer analysis does not alter the major conclusions about the differences between Cs and Vs.

Shifts in C-V Response Form Classification

The general hypothesis advanced by Theios (1972) and, therefore, all of the specific mathematical models based on that hypothesis, also have an important implication about response topography classification. They imply that, regardless of the overall classification of a subject as C or V, a subject's first few CRs should be C-form. This results from the hypothesis that even Vs go through a "conditioned" state during which C-form responses tend to be given before they enter a "voluntary" response state where V-form responses tend to be given. Therefore, the general hypothesis predicts that overall classification of a subject as C or V should be independent of a C or V classification based only on the first few CRs. Accordingly, overall Cs and Vs were also classified as Cs or Vs based on their first five CRs. Of the 60 overall Cs, 48 (80%) were also classified as Cs based on their first five CRs. Of the 52 overall Vs, only 13 (25%) were classified as Cs based on their first five CRs. This pattern was obtained in each of the five experimental groups so that combining the data does not ignore any group differences. The overall classification and initial classification are not independent. Rather, overall Cs tend to give C-form responses initially and overall Vs tend to give V-form responses initially. This lack of independence is confirmed by a significant chi-square test for association of overall C-V classification and initial C-V classification, $\chi^2(1) = 33.98, p < .001$.

CONCLUSIONS

Both the finite integer and response topography analyses suggest that the general hypothesis about Cs vs. Vs and the discrete-state formalization of that hypothesis advanced by Theios (1972) are inaccurate at the level of the individual human subject. Although such analyses do not disprove the idea that Vs are "voluntary" responders, the analyses are consistent with Grant's (1972) suggestion that it is inaccurate to think of the V-form CR as simply a self-instructed eyelid closure. When combined with recent reports of different visual field or cerebral hemisphere of stimulus presentation effects for Cs vs. Vs during both conditioning and choice reaction time tasks (Hellige, 1975), the present results suggest that the differences between Cs and Vs are not as simple as the Spence-Taylor and Theios formulations would suggest.

REFERENCES

GRANT, D. A. A preliminary model for processing information conveyed by verbal conditioned stimuli in classical differential conditioning. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current theory and research.* New York: Appleton-Century-Crofts, 1972, 29-63.

HARTMAN, T. F., & ROSS, L. E. An alternative criterion for the elimination of "voluntary" responses in eyelid conditioning. *Journal of Experimental Psychology*, 1961, **61**, 334-338.

HELLIGE, J. B. Hemispheric processing differences revealed by differential conditioning and reaction time performance. *Journal of Experimental Psychology: General*, 1975, in press.

HELLIGE, J. B., & GRANT, D. A. Eyelid conditioning performance when the mode of reinforcement is changed from classical to instrumental avoidance and vice versa. *Journal of Experimental Psychology*, 1974, **102**, 710-719. (a)

HELLIGE, J. B., & GRANT, D. A. Response rate and development of response topography in eyelid conditioning under different conditions of reinforcement. *Journal of Experimental Psychology*, 1974, **103**, 574-582. (b)

PROKASY, W. F. Developments with the two-phase model applied to human eyelid conditioning. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current theory and research.* New York: Appleton-Century-Crofts, 1972, 119-147.

SPENCE, K. W., & TAYLOR, J. A. Anxiety and strength of the UCS as determiners of amount of eyelid conditioning. *Journal of Experimental Psychology*, 1951, **42**, 183-188.

THEIOS, J. Finite integer models for learning in individual subjects. *Psychological Review*, 1968, **75**, 292-307.

THEIOS, J. Formalization of Spence's dual-process model for eyelid conditioning. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current theory and research.* New York: Appleton-Century-Crofts, 1972, 100-118.

ZAJANO, M. J., & GRANT, D. A. Response topography in the acquisition of differential eyelid conditioning. *Journal of Experimental Psychology*, 1974, **103**, 1115-1123.

ZAJANO, M J., GRANT, D. A., & SCHWARTZ, M. Transfer of differential eyelid conditioning: Effects of semantic and formal features of verbal stimuli. *Journal of Experimental Psychology*, 1974, **103**, 1147-1152.

NOTES

1. Theios (1968) shows that if L_g and L_h are the maximum likelihoods of a given response sequence under the hypothesis that the process under investigation has g and h states, respectively (h> g), then $-2\log_e(L_g/L_h)$ is approximately distributed as chi-square with 3(h-g) -1 df.

2. Group CL 60 in the present paper consists of subjects randomly chosen from those used to obtain Group AVO-CL60 reported by Hellige and Grant (1974a). Group AV 60 in the present paper is Group CLO-AV60 reported by Hellige and Grant (1974a). Groups CL 100, AV 100, and YK 100 are reported in Experiment I of Hellige and Grant (1974b) as Groups CL, AV, and YK, respectively.

3. The author would like to thank John Theios for providing a copy of a finite integer analysis Fortran program which compares one, two, three, and four-state Markov models for each individual subject protocol.

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