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RELATIONSHIP BETWEEN SCR, HEART RATE AND INFORMATION PROCESSING

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This study was designed to investigate the relationship between the amount of information processing in concept learning (CL) and autonomic physiological activity as measured by skin conductance response (SCR). Heart rate (HR) was also measured. Two conceptual rules were used: a conjunctive and an inclusive disjunctive concept. The results indicated that the SCR rose with increasing amount of information processing at the feedback during CL. Furthermore, it was shown that SCR increased with increasing difficulty of the conceptual rule. HR appeared not to vary with amount of information processing, nor with type of concept. In the conjunctive series, however, there was a significant difference between HR at stimulus presentation and HR at feedback.

1. Introduction

Lacey's (1967) intake–rejection hypothesis states that intake of information (external information processing) results in directional fractionation: decrease of heart rate (HR) and increase of the skin conductance response (SCR), whereas rejection of information (internal information processing) results in increase of both HR and SCR. This hypothesis states among others that differences in information processing – either cognitive or perceptual – are accompanied by different patterns of autonomic physiological activity. Concept learning (CL) tasks can be considered as information processing tasks (e.g. Johnson, 1972; Klix, 1971; Pishkin and Wolfgang, 1964). So it is justified to expect that changes in the amount of information processed during CL are reflected in autonomic physiological activity measures. This relation was found by Zimmermann (1971), Pishkin and Wolfgang (1964) and Pishkin and Shurley (1968).

Zimmermann's main conclusions were (1) that at sections of increased cognitive activity in CL there was an increase in intensity of the skin resistance response (SRR); (2) that the SRR varied dependent on the amount of uncertainty reduced by feedback; and (3) that the SRR varied with type of concept, dependent on the degree of difficulty of the concept. Pishkin and Wolfgang (1964) found in a CL task, among other things, a relationship between the amount of information input (task complexity), which was assumed to be related to information processing, and muscle action potentials (MAPs). Pishkin and Shurley (1968) confirmed this result and found also that the number of spontaneous SCRs varied with the amount of information processing.

However, the experimental setups employed can be criticized. In Zimmermann's experiment eight different stimuli were repeatedly presented in the same order, starting with all positive instances followed by all negative ones. With this procedure it was possible that the subjects predicted the response category correctly without having learned the concept, either by associate learning, or by learning the feedback sequence of the positive instances followed by the negative ones. Furthermore, one of the conceptual rules employed by Zimmermann was a disjunctive exclusive concept. However, such a concept is not completely solvable when using bivalued dimensions: only the relevant dimensions can be found, not the relevant values. Finally, a better SCR measure than the skin resistance Zimmermann used is conceivable, namely the skin conductance (Lykken and Venables, 1971).

Pishkin and Shurley (1968) used a self-paced CL task. To prevent habituation of specific SCR amplitudes subjects were given a tone, to which they were previously aversely conditioned, for 2 sec at 1 min intervals. The SCR amplitude was measured at each tone. The spontaneous SCR measure consisted of the number of SCRs between the tones. As the task was self-paced it is likely that in a simple task more stimuli and consequently more responses and feedback could be processed during the periods between the tones than in a more complex task. Stimuli, motoric responses and feedback all elicit SCRs. Hence, a decrease in number of SCRs can be predicted as complexity increases. This relationship was indeed found. The possibility of this being an artifact, however, was not considered. In addition, it seems to be better to measure the specific SCR amplitude at the feedback instead of at the tone, because information processing is likely to be most intensive at the time of feedback. Therefore, differences in task complexity should be most salient during the feedback. Measuring the SCR amplitudes during the tone instead of during the feedback could therefore have caused the lack of relationship Pishkin and Shurley found between specific SCR amplitude and task complexity.

The main purpose of this study was to investigate the relationship between (1) the SCR and the amount of information processing, and (2) the SCR and the degree of difficulty of the conceptual rule, in such a way as to rule out the above-mentioned points of criticism. The HR was also measured. This was done for explorative reasons. It could be assumed that during a CL task the stimulus period would tend towards the intake side, whereas the feedback period would tend more towards the rejection side on the intake–rejection dimension. If this assumption holds and if the difference in information processing is large enough to show any difference in HR among both periods, then, according to the intake–rejection hypothesis, it can be predicted that HR will be higher at feedback periods than during stimulus presentation.

2. Method

2.1. Task

In a CL task the conceptual rule was varied in two series. In one of the series the subjects had to learn a conjunctive concept (series C); in the other a disjunctive inclusive concept (series D). Each subject received both series, half of the subjects first solving series C, the other half series D. Subjects had to learn the relevant attributes as well as the rule of the appropriate concept, although they knew in advance that only two rules were possible. The subjects did not know how many problems they had to solve.

The series were terminated either when the subject correctly classified three successive stimuli and mentioned the correct concept, or, if this did not occur, after 40 trials.

2.2. Subjects

Ten male and 10 female psychology freshmen participated in the experiment, which was considered part of their training. Five male and five female subjects received one order of the two experimental series, the remaining 10 subjects received the other order.

2.3. Stimulus material

The stimulus material consisted of schematic faces. Each face was composed of one value of each of four dimensions: short or long hair, eyes opened or closed, laughing or a mournful expression, and moustache or beard. Hence, 16 different faces were possible.

2.4. Apparatus

The experiment room was dimly illuminated and soundproof. A projector (Carousel model type 2) was located outside the room. Stimuli and feedback (showing either a plus or a minus) were projected on a frosted glass window in front of the subject. Inside the room a card, showing the code which the subject had to use in formulating his hypothesis about the concept, was suspended next to the window. The subject gave his hypothesis verbally through a microphone. On the writing-hand-side elbow rest of the subjects chair two buttons were fixed, by means of which he had to give his categorization response (R). There were two R categories: a positive and a negative category. R, SCR and HR were recorded with the aid of a Beckman eight-channel polygraph (type R 411 dynograph). Projector impulses from the timer were automatically recorded on the polygraph.

SCR was measured by a constant 0.5 V voltage bridge. AgCl electrodes, 7.5 mm in diameter, were attached to the volar surface of the distal phalanges of the second and third finger of the non-writing hand for five subjects. Because of difficulties with these electrodes, arising during the experiment, the SCR of the other 15 subjects was measured by means of AgCl electrodes, 15 mm in diameter, which were attached to the palmar surface of the non-writing hand. The HR electrodes, also 15 mm in diameter, were attached to the breast according to lead I. The inactive electrode was placed on the lateral forearm of the non-writing arm. All electrodes were affixed with electrode paste of KCl composition.

2.5. Procedure

After making the subject familiar with the equipment, the recording leads were attached and the subject was seated in the soundproof room. Instructions were then given as to the nature of the task, the means of responding and the meaning of the feedback. After a training series, to make sure that the subject had understood the instructions, and after 5 min rest, the first series was started. After reaching criterion in the first series a few minutes' rest followed, after which the second series was started. The trials of both series were composed as follows: after 15 sec stimulus presentation the subject immediately had to give his categorization R (plus or minus); 8 sec later feedback was shown during 5 sec (the correct categorization: a plus or a minus). After 10 sec the subject had to give his hypothesis about the concept within 13 sec, indicated by the burning of a green light; 9 sec later the next stimulus was presented. The order of presentation of the stimuli was the same for each subject. With the restriction that in the stimulus sequence only one value at a time changed, the order of presentation was determined at random. This order was repeated until the subject had reached criterion.

2.6. Quantification of data

The SCR was measured as the greatest conductance change (ΔSC) beginning between 1 and 4 sec after the onset of the feedback. Within the feedback two types were distinguished: confirming and infirming feedback. It was assumed that more information was processed after infirming feedback than after confirming feedback. For after infirming information the subject has to choose a new hypothesis, whereas confirming information evidences the hypothesis the subject holds. HR was measured within 10 sec after onset of both the feedback and the stimulus. In this way, however, possible differences in HR variability within these 10 sec caused by HR deceleration and HR acceleration [the (bi)phasic component of the arousal R], were not accounted for.

Non-parametrical methods were used for the data analysis. Mainly intraindividual comparisons were made on account of interindividual differences in autonomic physiological activity, hence the SCRs were not logarithmed.

3. Results

The results are summarized in table 1.

3.1. Number of trials to criterion

In series C and D one and eight subjects, respectively, did not learn the concept within 40 trials. For series C the number of trials to criterion appeared to be significantly lower than for series D (Wilcoxon matched-pairs signed ranks test, $p < 0.05$).

Within series C subjects changed significantly more frequently to conjunctive than to disjunctive hypotheses (Wilcoxon matched-pairs signed ranks test, $p < 0.05$). Within series D this difference was insignificant. However, in the first half of series D the subjects changed significantly more often to conjunctive hypotheses than in the second half (sign test, $p = 0.001$).

Of the hypotheses tested by a subject in a series, 88% had not been tested before. Of the total number of trials to criterion 3% were left out of consideration because either no hypothesis was given or the hypothesis was held after infirmation or changed after confirmation.

3.2. Skin conductance response

In both series C and D the relationship between the amount of information processing and SCR turned up in a significantly higher SCR at infirming than at confirming feedback (sign test, $p = 0.011$ and $p = 0.021$, respectively).

In accordance with Sokolov's (1969) model of the orientation reaction (OR) it was assumed that a hypothesis becomes progressively more probable with increasing number of confirmations of that hypothesis. The more probable a hypothesis is to the subject, the greater the difference between expected feedback and actual infirming feedback. Since SCR is an indicator of the magnitude of the OR, it was expected that SCR at infirming feedback would increase with increasing number of previous confirmations of subjects hypothesis. The SCR data at infirming feedback were classified into four categories, in accordance with the number of directly preceding confirmations of a hypothesis (0, 1, 2 and $\geqslant 3$). To provide enough data in each group, the data of series C and D were taken together. It turned out that SCR increased with increasing number of trials of confirmation before infirmation (Friedman two-way analysis of variance, $p < 0.05$).

To demonstrate the effect of habituation, both series were Vincentized (in equal parts for each subject) to correct the difference in number of trials between subjects. The SCR appeared to decrease significantly throughout each of the two series (Friedman two-way analysis of variance, $p < 0.01$). Between the series, however, habituation did not occur (sign test, $p > 0.05$). With respect to the relationship between SCR and the difficulty of the conceptual rule, the data yielded no significant

Table 1
Number of trials to criterion, mean SCR for confirming (conf.) and infirming (inf.) feedback and mean HR for stimulus (St) and feedback (F) for each subject.

Order of presentation		Number of trials to criterion		Mean SCR at feedback (in μmho)				Mean HR (beats/min)			
		Series		Series C		Series D		Series C		Series D	
C–D (subjects)[a]	D–C (subjects)[a]	C	D	conf.	inf.	conf.	inf.	St	F	St	F
1m		10	40	5.15	4.73	2.38	2.05	84.60	85.20	83.85	84.00
2m		18	14	2.74	3.65	3.32	3.02	73.00	73.67	69.43	68.57
3m		21	40	1.43	1.99	1.02	1.50	62.00	62.00	60.15	60.00
4m		36	17	2.05	2.65	2.21	1.77	88.67	89.00	82.59	81.53
5m		3	16	1.52	no data	0.74	1.24	96.00	92.00	94.88	94.88
	6m	40	36	0.86	0.79	0.61	0.73	83.70	84.15	89.50	91.22
	7m	18	36	0.83	1.11	1.25	1.29	89.00	90.33	93.83	95.50
	8m	8	40	0.19	0.05	0.23	0.39	77.25	75.00	81.00	80.25
	9m	20	37	0.30	0.34	0.23	0.21	77.70	76.80	81.57	83.73
	10m	8	17	0.32	0.99	0.79	1.39	68.25	68.25	67.41	70.24
11w		7	32	0.45	0.60	0.42	0.44	105.71	107.71	87.19	88.13
12w		3	33	2.24	no data	1.46	1.89	80.00	86.00	78.55	80.73
13w		7	18	0.02	0.05	0.05	0.07	78.00	79.71	85.41	83.29
14w		10	4	0.60	1.25	0.60	1.73	75.80	75.80	82.50	84.00
15w		20	40	0.71	1.13	1.36	2.14	62.10	65.10	60.77	60.15
	16w	7	40	2.22	4.48	1.60	3.52	54.75	56.25	60.30	60.00
	17w	4	40	0.26	0.26	1.20	1.71	97.50	97.50	100.95	102.00
	18w	3	35	0.86	no data	1.01	1.13	102.00	98.00	110.06	110.23
	19w	4	40	0.19	1.46	0.74	1.08	118.50	120.00	124.95	124.95
	20w	15	40	0.65	0.99	0.94	0.16	81.20	82.40	87.60	86.75

[a] For subjects 1, 6, 11, 12 and 16 the SCR electrodes were attached to the fingertips; m = man, w = woman.

difference in SCR between series C and D (sign test, $p > 0.05$). This lack of difference could have been caused by habituation, for series C required less trials than series D. Therefore, the same number of trials for series C and D were compared by taking the series with the least number of trials. The results showed the tendency of a smaller SCR at series C (sign test, $p = 0.08$). No significant difference in number of infirmations between both series was found (sign test, $p > 0.05$), so higher SCRs at infirmation could not have produced this tendency. The data yielded a significant correlation of the difference in SCR and the difference in number of trials between both series ($r_s = 0.61$, $p < 0.05$). By this method individual differences were minimized.

The difference in SCR between both series was not caused by the difference in number between both types of feedback (plus or minus; sign test, $p > 0.05$). The data yielded no significant difference between the SCR when testing a conjunctive hypothesis, and the SCR when testing a disjunctive hypothesis (sign test, $p > 0.05$).

3.3. Heart rate

Heart rate appeared to be significantly higher during feedback than during stimulus presentation for series C (sign test, $p = 0.038$). At series D this difference was insignificant (sign test, $p > 0.05$). The data showed no significant difference in HR at confirming and at infirming feedback (sign test, $p > 0.05$). In adaptation, it turned out that HR in the last minute before the beginning of the first series tended to be higher than HR in the last minute before the beginning of the second series (sign test, $p = 0.058$). Furthermore, HR during the first series was significantly higher than HR during the second series (sign test, $p = 0.001$). After Vincentizing both series in three parts, HR appeared to decrease significantly throughout each of both series (Friedman two-way analysis of variance, $p < 0.05$ and $p < 0.01$ at series C and D, respectively). No significant difference in HR between series C and D could be demonstrated (sign test, $p > 0.05$).

A comparison of an equal number of trials for both series yielded no significant difference (sign test, $p > 0.05$). This results holds after correction for difference in starting level of both series.

4. Discussion

This study showed that more subjects learned the conjunction than the disjunction, and that less trials were required to learn the conjunction. Hence, it is concluded that the disjunction is a more difficult concept to learn than the conjunction. This conclusion agrees with many other studies (e.g. Conant and Trabasso, 1964).

The results: (1) that within the conjunctive series subjects tested more conjunctive than disjunctive hypotheses, and (2) that within the disjunctive series most subjects started testing conjunctive hypotheses, are in agreement with those of Hunt and Hovland (1960) that subjects more frequently state conjunctive rather than disjunctive conceptual rules when both are possible.

The difference between the numbers of both types of hypotheses tested could not have influenced possible differences in SCR at feedback between both series, because of the lack of difference between SCR in testing disjunctive and conjunctive hypotheses.

The significant higher SCR at infirming than at confirming feedback seems to justify the conclusion that the results of Zimmermann (1971) and Pishkin and Shurley (1968) were due to the relationship between SCR and the amount of information processing and not to artifacts of their experimental design,

Another demonstration of the relationship between SCR and the amount of information processing is given by the result that the more often a hypothesis was confirmed before, the larger the SCR appeared to be at the moment it was infirmed. This result is in agreement with Sokolov's (1969) model of the OR, which predicts increasing SCR with increasing discrepancy between the expectation (i.e. the number of confirmations of the subject's hypothesis) and the actual situation (i.e. infirming feedback). The relationship between magnitude of SCR and number of confirmations before infirmation is also relevant to mathematical learning models. Two versions of mathematical all-or-none learning models can be distinguished: the conditioning interpretation and the strategy–selection model (Kintsch, 1970). According to the first, learning is possible after confirming as well as after infirming feedback, whereas the second states that subjects can learn only from infirming feedback. Kintsch concludes that the strategy–selection model gives better results. The influence of the number of confirmations which precedes an infirmation on SCR points to the conditioning interpretation. The result, however, that in 97% of the cases after confirmation the confirmed hypothesis was held, points to the strategy–selection model, which predicts that only after infirmation a new hypothesis is selected. The result that 88% of the hypothesses were not tested before indicates that subjects are not choosing at random from the set of possible hypotheses – a frequently assumed axiom in mathematical learning models.

As already pointed out in this discussion, the disjunctive series is considered the more difficult task. This difference in difficulty tended (p = 0.084) to appear also in the SCR magnitude after correction for the significant influence of habituation. A positive relationship between SCR and the number of trials to criterion was also shown after correction for individual differences in SCR reactivity. Hence, the conclusion seems justified that the data support the hypothesis of an increasing SCR with increasing degree of difficulty of the conceptual rule, but only if corrected for habituation and individual differences. This conclusion is in accordance with Zimmermann (1971) and Kahneman, Tursky, Shapiro and Crider (1969).

From the results with respect to HR it can be concluded that HR did not vary with the amount of information processing nor with the degree of difficulty of the conceptual rule. It seems justified to conclude that HR is a less suitable indicator of the amount of information processing than SCR in CL. Perhaps HR variability is a better indicator.

According to Lacey's intake–rejection hypothesis, it was assumed that HR would be higher at feedback than during stimulus periods. The results indicate that in the conjunctive series HR varied in agreement with the prediction by Lacey's hypothesis. In the disjunctive series no difference was found between HR at feedback and during presentation of the stimulus. This could be due to the distinction between intake and rejection which was too small to permit a significant difference in HR. Given that our supposition holds, Lacey's hypothesis is not challenged by our results.

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