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Anxiety and Learning-Performance*

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Summary. A theory proposing a dual effect of anxiety on learning performance is presented. On the one hand anxiety is assumed to facilitate threat relevant responses. On the other hand it diminishes threat irrelevant responses. Additionally, each response in a learning situation is classified as being either task relevant or task irrelevant. Learning is assumed to strengthen the task relevant responses. Together these two classifications determine four response categories. Theoretical variables considered in the theory are the individual's anxiousness and learning ability and the stress, task difficulty, and task repetition of the situation. Kind of learning task and kind of stress situation determine the combination of the four response categories that has to be considered in analysing performance data. Specific models derived from this general approach are supported by reanalysing the data from three published experiments (eyelid conditioning, serial anticipation learning, positional motor learning). The empirical validity of this dual effect theory and also its relationship to other theories is discussed and a reinterpretation in terms of stimulus utilization and attention regulation is provided.

Key words: Anxiety, Learning, Performance, Stress.

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Angst und Lernleistung

Zusammenfassung. Zur Wirkung von Angst auf Lernleistungen wird eine Theorie vorgestellt, die einen zweifachen Effekt von Angst postuliert. Angst fördert bedrohungsrelevante Reaktionen und hemmt bedrohungsirrelevante Reaktionen. Zusätzlich zu dieser Klassifikation von Reaktionen wird zwischen aufgabenrelevanten und aufgabenirrelevanten Reaktionen unterschieden, wodurch vier Arten von Reaktionen entstehen. Durch Lernen werden die aufgabenrelevanten Reaktionen gestärkt. Die Effekte von Ängstlichkeit und Lernfähigkeit der Personen und von Streß, Aufgabenschwierigkeit und Aufgabenwiederholung der Situationen werden in der Theorie abgebildet. Es hängt von der Art der Lernaufgabe und der des Stresses ab, welche Kombination der vier Reaktionsarten bei der Analyse von Leistungsdaten berücksichtigt werden muß. Durch die Analysen von drei veröffentlichten Experimenten (Lidschlag-Konditionierung, Serielles Antizipationslernen, Erwerb motorischer Positionierungsreaktionen) werden die aus dem theoretischen Ansatz abgeleiteten Modelle gestützt. Die empirische Validität dieser Theorie und ihre Beziehung zu anderen Theorien, sowie eine Reinterpretation im Sinne des Nutzbarmachens von Stimuli und der Aufmerksamkeitsregulation werden zur Diskussion gestellt.

Stichwörter: Angst, Lernen, Leistung, Streß.

During the last 30 years a lot of empirical and theoretical work has been presented on the problem of the effect of anxiety on learning and other performance (for general reviews see e. g. Fröhlich, 1966; Gärtner-Harnach, 1972; McReynolds, 1975). One of the first theories on this topic was developed by Spence (1956, 1958) and Taylor (1956) on the basis of Hull's theory. It tried to explain the effects of different types of anxiety in different learning situations within a homogeneous and comparitively precisely formulated framework. This level has not been achieved by any competing theory. The present paper again attempts to make a small step in this direction. Some approved assumptions of other theories will be adopted, the relationship of the present framework to these theories will be inspected in the final discussion.

Theoretical Framework

A traditional assumption (e. g. Müller and Pilzecker, 1900) is that observable behavior is the result of compatible or competitive response tendencies. The first question to be asked is which kinds of response tendencies are effective in an "anxiety and performance situation", the second, how do they compete with respect to the required performance, and finally, which factors determine their strength.

Classes of Response Tendencies

In accordance with other authors it is assumed that a stress situation, i.e. a situation which is experienced as threatening for more than a short period of time (Spielberger, 1966, 1975), has two consequences: (a) An emotional process, usually referred to as anxiety, is aroused. The purpose of this emotional component will be discussed subsequently. (b) Information processing is stimulated in order to choose a response from a response repertoire that is appropriate to the threat and that will eliminate it. These responses can either be innate species-specific defence reactions (e. g. Bolles, 1970), or they can be the result of the individual's learning history. Typical examples in human beings are the eyelid reflex, escape movements, and cognitive self or situation related responses, as postulated and investigated by Mandler and S. B. Sarason (1952), S. B. Sarason and Mandler (1952), and I. G. Sarason (1958, 1973, 1978). With respect to the experienced threat these are relevant responses. Their underlying response tendencies compete with irrelevant response tendencies aroused at the same time by other needs or motives. One can therefore distinguish between relevant and irrelevant response tendencies with regard to the experienced threat.

In a learning experiment, assuming that the subject is motivated to comply with the instructions, information processing is stimulated by each task with the aim of giving the correct answer as defined by the experimenter, i. e. a response relevant to the specific task. Its underlying response tendency competes with irrelevant response tendencies which are likewise evoked by the task but which are not directed towards the correct answer. Thus, one can also distinguish between relevant and irrelevant response tendencies with respect to the specific task.

Combining these two classifications of response types yields four possible types of responses in mastering learning tasks in situations which are experienced as threatening. In Table 1 the four types of responses are denoted by capital letters. The information components of the response tendencies have different degrees of strength, u, that are traditionally referred to as association strength. However, Table 1 contains the strength of the actually effective response tendencies, v. v is not only depending on u but also on the actual anxiety level α in a way defined below.

An example for a response tendency of type *RR* is the tendency to react with a conditioned eyelid response in a classical conditioning experiment; type *RI* is, for instance, the tendency to answer with the correct trigram in a serial anticipation learning experiment; type *IR* may be the tendency to think "the task is too difficult" in the same experiment; type *II* may be the tendency to answer with the german „bekommen“ (get) when presented with the stimulus "become" in a vocabulary learning task by pair associates.

Table 1. Response classification

			Related to the experienced threat relevant $v_{\cdot R}$	irrelevant $v_{\cdot I}$
Related to the learning task	relevant	$v_{R\cdot}$	v_{RR}	v_{RI}
	irrelevant	$v_{I\cdot}$	v_{IR}	v_{II}

These examples already indicate that dependent on the type of task different combinations of response types should be considered.

Transforming Response Tendencies into Response Probabilities

Usually the relative frequency of correct responses is used as the dependent variable in a learning experiment. Thus the question is raised as to the probability p_r of a correct response being dependent on the strength of the actually effective task-relevant and task-irrelevant response tendencies $v_{R\cdot}$ and $v_{I\cdot}$. Because of the assumed competition between these types of response tendencies, p_r should be a monotonically increasing function of $v_{R\cdot}$ and a monotonically decreasing function of $v_{I\cdot}$. The frequently applied "behaviour ratio assumption" is made (e. g. Thurstone, 1930; Estes, 1950; Luce, 1959; Rasch, 1960; the expression is chosen with reference to Tolman, 1938). According to this assumption the response probability is the strength of the relevant response tendency divided by the sum of the strength of all response tendencies. For a task with one relevant and one irrelevant actually effective response tendency (1) is obtained.

$$p_r = v_{R\cdot}/(v_{R\cdot}+v_{I\cdot}), \quad \text{where} \quad 0 \leqslant v_{R\cdot}, v_{I\cdot} < \infty \tag{1}$$

There may exist actually effective response tendencies that neither contribute to $v_{R\cdot}$ nor compete with $v_{R\cdot}$, these would not be contained in (1).

The Effect of Anxiety

The strength of the actually effective response tendencies v depends on the strength of the information component u and on the actual anxiety level α. The question is "how?".

Two different simultaneously acting effects of anxiety are assumed in order to account for a reaction suitable to the extent of the individual's experienced threat as well as to other actual needs of the individual. The effect of this emotional component differs for the threat relevant and irrelevant informational components.

The strength of an effective threat relevant response tendency is directly proportional to the anxiety level and to the strength of the threat relevant informational component $u_{\cdot R}$:

$$v_{\cdot R} = u_{\cdot R}\,\alpha, \quad \text{where} \quad 0 \leqslant v_{\cdot R}, u_{\cdot R}, \alpha < \infty \tag{2}$$

The strength of the threat irrelevant informational component $u_{\cdot I}$ is inhibited by anxiety, so that the resulting effective tendency $v_{\cdot I}$ competes, according to the level of anxiety α, less strongly, or even not at all, with $v_{\cdot R}$. A threshold concept is assumed here according to which the strength $u_{\cdot I}$ becomes effective only to such a degree as to which it exceeds the anxiety threshold α:

$$v_{\cdot I} = (u_{\cdot I} - \alpha)^+, \text{ where } 0 \leqslant v_{\cdot I}, u_{\cdot I} < \infty \text{ and } (\kappa)^- = \begin{cases} \kappa & \text{for } \kappa > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Besides the classification of response tendencies, equations (2) and (3) are the most important assumptions of the theoretical framework. In order to be able to test the theory developed so far it is, furthermore, essential to make assumptions about the functional dependency of the emotional and informational components on those

theoretical variables which represent empirical variables or variations. These assumptions will be specified in the following two sections.

Determinants of Anxiety

With reference to Spielberger's (1966, 1972, 1975) distinction between state anxiety and trait anxiety it is assumed that actual anxiety α (as state) is a monotonically increasing function of (a) the anxiousness a of an individual (as trait) with regard to the specific kind of threat, and of (b) the stress s of the threatening situation. Anxiety should not be experienced by an individual totally unanxious with respect to the type of threat or in a situation totally free of stress. Therefore the following simple assumption is plausible:

$$\alpha = a\,s, \quad \text{where} \quad 0 \leqslant a, s < \infty \tag{4}$$

Determinants of Learning

Because it is intended to apply the theoretical framework to data from learning experiments with commonly used experimental variations it is sufficient to consider the informational components or associative strength $u_{R\cdot}$ and $u_{I\cdot}$ under the aspects of their functional dependency on those variables that represent the effects of usual experimental variations.

For simplicity it is assumed that the task irrelevant component $u_{I\cdot}$ is constant for all subjects, tasks, and learning trials in a specific learning experiment:

$$u_{I\cdot} = \text{constant}, \quad \text{where} \quad 0 \leqslant u_{I\cdot} < \infty \tag{5.1}$$

The task relevant component $u_{R\cdot}$ should be a monotonically increasing function of the stimulus relevance or stimulus intensity c, of the subject's learning ability d for the special type of tasks, of the task's easiness e, and of f_n, the training effect of n trials. No task relevant component should be effective if any of these variable attained its minimum value of zero. The following simple relationship again fulfills the stated conditions:

$$u_{R\cdot} = c\,d\,e\,f_n, \quad \text{where} \quad 0 \leqslant c, d, e, f_n < \infty \tag{5.2}$$

How does the training effect f_n depend on the number n of trials? For simplicity a linear function (6) is assumed, where fn_o denotes the pre-experimental experience or the guessing possibility with respect to the task. (n_o denotes the number of learning trials corresponding to the amount of pre-experimental experience.)

$$f_n = fn + fn_o = f(n+n_o), \quad \text{where} \quad 0 \leqslant f < \infty \quad \text{and} \quad n, n_o = 0, 1, 2, \ldots \tag{6}$$

The quantity f represents the effect of one learning trial. It is assumed in (6) that this effect is the same for all trials. The assumption of a linear learning function may only be valid for certain learning tasks. It is however not essential for the theoretical framework. For special applications other functions may be more appropriate.

Empirical Evidence

In the following sections empirical evidence demonstrating the appropriatness of the theoretical approach is presented. Only few of the numerous experimental studies on the effect of anxiety on learning performance will be selected. The choice was guided by considering different types of learning tasks and of stress situations and by a kind of data presentation suitable for analysis. This excludes most studies from consideration because the usual summary account of results does not provide a sufficient basis for evaluation within the theoretical framework.

In analysing the experimental data I renounce to the application of statistical procedures for parameter estimation and model testing because even the selected data were published in too condensed form. Instead, the REC-technique (Response Evocation Characteristic), suggested by Grice (1968, 1971, 1972), will be applied. This technique became especially well known in connection with the so-called ROC-curves (Receiver Operating Characteristic). Generally, empirically testable predictions of a model will be obtained as follows: A functional relationship between the values of the dependent variable for two levels of one independent variable under variation of the remaining independent variables is derived. The empirically obtained correlative values are then plotted against each other and the agreement with the function derived from the model is tested by inspection. For all predictions a transformation of probabilities p_r and relative frequencies of correct responses into odds, $p_r/(1-p_r)$, has proved to be appropriate. Model-derived functions are straight lines after this transformation and are thus easily comparable with the empirically observed relationships.

Classical Conditioning of the Eyelid Reflex

A typical eyelid conditioning experiment using a $2 \times 2 \times 2 \times 8$ design was reported by Beck (1963). The two between-group variables were: (a) the subjects' anxiety level, which was choosen as being either high (MAS-high) or low (MAS-low) by selecting female subjects with extreme values on Taylor's (1953) Manifest Anxiety Scale (MAS), (b) the intensity of the unconditioned stimulus (UCS), which was either a strong (UCS-strong) or a weak (UCS-weak) air puff on the cornea. The two within-group variables were: (c) the intensity of the conditioned stimulus (CS), which was a loud (CS-loud) or a soft (CS-soft) tone presented in a balanced random sequence, so that an adaptation to one of the two stimuli was impossible, and (d) eight blocks with 10 learning trials each, five with the loud and five with the soft CS. The dependent variable was the relative frequency of conditioned responses (CR). For the current analysis the results of this experiment are taken from Grice (1968, Figure 11) who dichotomized Beck's trial variable in order to obtain more stable values of the dependent variable for fitting his model to the data. The response frequencies are presented in Table 2.

The first question is which of the four response tendencies of Table 1 should be considered in analysing this experiment. The conditioned eye lid response to be learned is considered as relevant with respect to the situational stress or the experienced threat evoked by the expectation of the air puff. The underlying response tendency is therefore of type *RR*. Further, it is assumed that a pre-experimental task-irrelevant response

Table 2. Relative frequencies of conditioned eyelid responses in Beck's (1963) experiment taken from Grice (1968)

			Early trials		Late trials	
			MAS-		MAS-	
			low	high	low	high
CS-soft	UCS-	weak	.16	.22	.29	.37
		strong	.40	.55	.60	.72
CS-loud	UCS-	weak	.38	.43	.49	.65
		strong	.63	.81	.83	.89

tendency not to give the conditioned response on presentation of the conditioned stimulus exists. This would be irrelevant with respect to the threat and is thus of type *II*.

Then, according to (1), the probability p_r of a conditioned response is $p_r = v_{RR}/(v_{RR} + v_{II})$. The odd-transformation yields $p_r/(1-p_r) = v_{RR}/v_{II}$. Consecutively substituting equations (2), (3), and (4) for the v's yields $p_r/(1-p_r) = u_{RR}\, a\, s/(u_{II} - a s)^+$, where a represents the varying anxiousness of the MAS groups and s represents situational stress, which was varied by the UCS-intensity.

When u_{RR} is further replaced by (5.2) attention must be paid to the fact that the subjects' learning ability and the easiness of the task were not varied. It is assumed that the corresponding variables d and e have values greater than zero. In this case these variables can be assigned a value of one because the possible constant deviation from that value would be contained in one of the remaining variables but does not enter into propositions on the level of a ratio scale. In (6) the assumption that no pre-experimental experience exists is plausible, i.e. $n_o = 0$.

Consequently model (7) results. Here c represents the effect of the intensity of the conditioned stimulus.

$$\frac{p_r}{1-p_r} = \frac{c f_n a s}{(u_{II} - a s)^+} = \frac{c f n a s}{(u_{II} - a s)^+} \tag{7}$$

Effect of CS-Intensity. One prediction of model (7) concerns the functional relationship between the odds from the CS-loud and the CS-soft condition under variation of the remaining variables. Representing the CS-soft condition by c_1 and the CS-loud condition by c_2 model (7) predicts the relationship of (8) for these odds.

$$\left(\frac{p_r}{1-p_r}\right)_2 = \frac{c_2}{c_1}\left(\frac{p_r}{1-p_r}\right)_1 \tag{8}$$

According to (8) a proportional relationship between the odds is predicted. The proportionality factor c_2/c_1 is interpreted as the ratio of the effects of loud and soft CS and should be greater than one. Because (8) is no longer dependent on the remaining variables, all the empirical odds should lie on the same straight line.

The relative frequencies in Table 2 were transformed into odds. Figure 1 displays the CS-loud-odds as a function of the CS-soft-odds. Prediction (8) is well fulfilled; according to the slope the loud CS was three times as effective as the soft CS.

Effect of Trials. Considering the functional dependence of the odds for late trials, n_2, on those for early trials, n_1, under variation of the remaining variable again a proportional relationship (9) results from (7).

$$\left(\frac{p_r}{1-p_r}\right)_2 = \frac{f_{n2}}{f_{n_1}}\left(\frac{p_r}{1-p_r}\right)_1 = \frac{n_2}{n_1}\left(\frac{p_r}{1-p_r}\right)_1 \tag{9}$$

Ordered from left to right in Figure 1 the values for each of the two trial conditions arise from the following anxiety conditions: MAS-low/UCS-weak, MAS-high/UCS-weak, MAS-low/UCS-strong, MAS-high/UCS-strong. Comparing the values of the late trials to those from the same anxiety condition in the early trials one recognises that each value for the late trials is about twice as high as the one from the early trials for both CS-conditions. That is to say, the predicted proportional relationship expressed by (9) is confirmed by the data. The proportionality factor f_{n_2}/f_{n_1} of about two seems to indicate a linear learning function as was assumed in (6). Considering, however, the grouping of trials into blocks a factor of three would be expected. That means assumption (6) has to be rejected for this experiment. However this assumption is, as already mentioned, not essential for the theoretical framework.

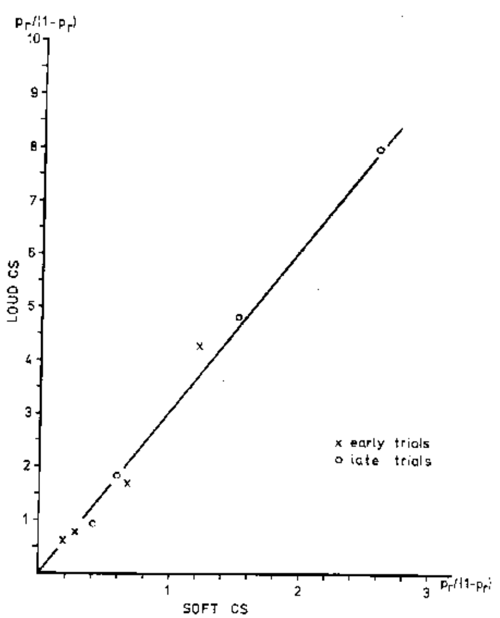

Fig. 1. REC-curve for intensities of the conditioned stimuli for the data in Table 2

Effect of Anxiousness and Stress. Transforming (7) into (10) makes it even more obvious that up to now the analysis did not test the central assumptions (2) and (3) about the effect of anxiety. Any other variation of the denominator in (10) by means of anxiety manipulation would have led to comparable results.

$$\frac{p_r}{1-p_r} = \frac{cf_n}{(u_{II}/as-1)^+} \tag{10}$$

Are these central assumptions about the effect of anxiety also supported by the data? Since easily testable REC-Curves for the two anxiety variables can not be derived from (7) the following procedure is adopted.

For the sake of simplicity the effect of the two anxiety varaibles a and s on the dependent variable p_r will be exemplified under one of the four CS/trial-conditions. I have selected the CS-soft/early-trials-condition, symbolized by the parameters c_1 and f_{n_1}.

Transforming (10) equation (11.1) is obtained for MAS-low, symbolized by a_1, and equation (11.2) for MAS-high, symbolized by a_2, where $j=1, 2$ characterizes the two UCS-conditions.

$$\left(\frac{1-p_r}{p_r}\right)_{1j} + \frac{1}{c_1 f_{n_1}} = \frac{u_{II}}{c_1 f_{n_1}}\,\frac{1}{a_1 s_j}, \quad \text{where} \quad \frac{u_{II}}{a_1 s_j} > 1 \tag{11.1}$$

$$\left(\frac{1-p_r}{p_r}\right)_{2j} + \frac{1}{c_1 f_{n_1}} = \frac{u_{II}}{c_1 f_{n_1}}\,\frac{1}{a_2 s_j}, \quad \text{where} \quad \frac{u_{II}}{a_2 s_j} > 1 \tag{11.2}$$

Dividing (11.1) by (11.2) shows that the ratios of the two left sides should be equal for both UCS-conditions j. For both UCS-conditions it should amount to a_2/a_1, the ratio of the anxiousness levels. The same holds for the two obtainable stress ratios s_2/s_1. The anxiousness ratios and the stress ratios can be estimated from the data in the two by two matrix for the CS-soft/early-trials-condition. But they can not be used for a model test because the unknown product $1/c_1 f_{n_1}$ has to be estimated from the data too. Therefore, also the data of the other three CS/trial-block-conditions have to be used. The same anxiousness ratios and stress ratios can also be estimated from equations corresponding to (11.1) and (11.2) for the other three conditions. If the eight estimates of each ratio deviate markedly from each other, then the appropriateness of the central theoretical assumptions about the effects of anxiety will be doubtful.

In order to test these predictions of the model at first the value of $1/c_1 f_{n_1}$ is estimated from all data in Table 2. The resulting value is 1.014. Then the three other values of $1/c_k f_{n_l}$ $(k, l=1, 2)$ are estimated on the basis of previous results. Dividing $1/c_1 f_{n_1} \approx 1.014$ (a) by $f_{n_2}/f_{n_1} \approx 2$ yields an estimate of 0.507 for CS-soft/late-trials, (b) by $c_2/c_1 \approx 3$ yields 0.338 for CS-loud/early trials, and (c) by $f_{n_2}/f_{n_1} \approx 2$ and $c_2/c_1 \approx 3$ yields 0.169 for CS-loud/late-trials. These values are added to the corresponding reciprocal odds calculated from Table 2. These sums and the ratios a_2/a_1 and s_2/s_1 are presented in Table 3.

On the basis of model (7) and of three estimated parameters it has been predicted that that the eight ratios a_2/a_1 as well as the eight ratios s_2/s_1 should be equal. This prediction is sufficiently well confirmed by the results in Table 3 supporting the theoretical assumptions (2) and (3), and also (4) on the effect of anxiousness and stress.

By this analysis the anxiousness with respect to the special type of threat of the MAS-high subjects is about 1.4 times that of the MAS-low subjects. The stress effect of the strong UCS is according to Table 3 about 2.5 times that of the weak UCS.

Table 3. Results on the combined effect of the MAS-level and the UCS-intensity for the data in Table 2[a]

			Early trials			Late trials		
			MAS- low	MAS- high	a_2/a_1	MAS- low	MAS- high	a_2/a_1
CS-soft	UCS-	weak	6.26	4.56	1.37	2.96	2.21	1.34
		strong	2.51	1.83	1.37	1.17	0.90	1.31
	s_2/s_1		2.49	2.49		2.52	2.47	
CS-loud	UCS-	weak	1.97	1.66	1.18	1.21	0.71	1.71
		strong	0.93	0.57	1.61	0.37	0.29	1.28
	s_2/s_1		2.13	2.90		3.24	2.41	

[a] The value within each cell of the 2×2-matrices is the sum of the reciprocal odd of the corresponding relative frequency taken from Table 2 and the corresponding estimate of $1/c_i f_{u_i}$. The marginal rows and columns display the ratios of the two corresponding cell values. For further explanation, see text.

Summarizing the analysis of Beck's (1963) data it can be stated that the results do not contradict model (7) which is derived from the general theoretical framework.

Serial Anticipation Learning of 'nonsense' Syllables

A typical serial anticipation learning experiment using 'nonsense' syllables and varying anxiousness and stress was conducted by Spielberger and Smith (1966). Contrary to most other studies of this kind they also considered the difficulty of the learning tasks.

Spielberger and Smith (1966) used a $2 \times 2 \times 2 \times 5$ experimental design. The two between-group variables were: (a) the degree of situational stress, manipulated by a so-called ego-involving instruction which was either given or was not given, (b) the anxiousness level of the male subjects, who had extremely high or low values on Taylor's (1953) Manifest Anxiety Scale. The two within-group variables were: (c) the learning difficulty of syllables which was determined by their position. Twelve syllables were used. The four from the extreme positions served as easy words, four from middle positions served as hard words. (d) Five blocks of five learning trials each. The dependent variable was the number of correct anticipations.

Concerning the difficulty effect Spielberger and Smith reported only the results for the groups with ego-involving instruction. Thus only these results, presented in Figure 2, will be analysed. Mean values of 1, 2, 3 and 4 correspond to relative frequencies of .25, .50, .75 and 1.0, respectively.

In analysing the data of Figure 2 the following response tendencies (according to Table 1) are assumed to be effective: (a) Recalling a nonsense syllable correctly does not belong to the pre-experimental repertoire of threat relevant responses. Thus the underlying task relevant response tendency is of the type *RI*. (b) The task irrelevant tendencies underlying the incorrect or missing reproductions are likewise threat

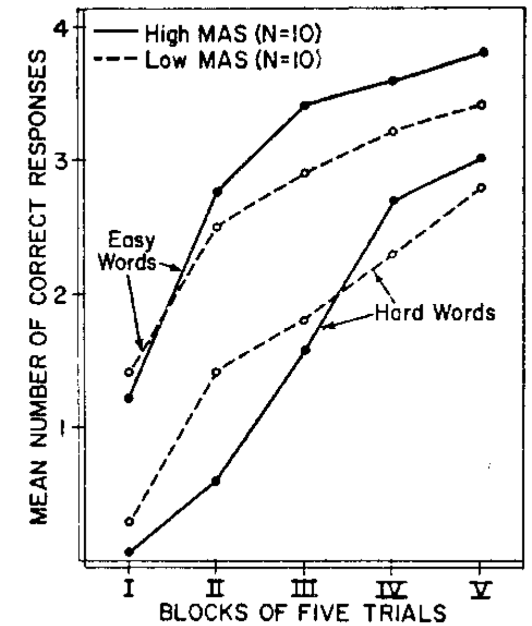

Fig. 2. Results of Spielberger and Smith's (1966) experiment on serial anticipation learning (Figure taken from Spielberger and Smith (1966), with kind permission)

irrelevant, i. e. of type *II*. (c) Apart from these there are other task irrelevant tendencies which are evoked not by the task but by the stress situation. These tendencies are threat relevant and of type *IR*.

According to (1) the probability of a correct reproduction is thus

$$p_r = \frac{v_{RI}}{v_{RI} + v_{II} + v_{IR}} \tag{12}$$

Transformation into odds and substitution of (2) and (3) into (12) yields

$$\frac{p_r}{1 - p_r} = \frac{(u_{RI} - \alpha)^-}{(u_{II} - \alpha)^- + u_{IR}\alpha} \tag{13}$$

Here the variables $u_{..}$ represent the corresponding information components or associative strength and α represents the actual anxiety level which varies with the different anxiousness levels in the stress situation. It is presupposed that the stress instruction is effective, i. e. $s > 0$ in (4).

In (5.2) the easiness variable e may completely represent the task difficulty and the variables c and d may be fixed at values of one according to the above-mentioned arguments. Pre-experimental knowledge or guessing of the correct answers can be almost excluded, i.e. $n_0=0$ in (6). Inserting (5) and (6) into equation (13) then yields model (14).

$$\frac{p_r}{1-p_r}=\frac{(efn-\alpha)^+}{(u_{II}-\alpha)^+ + u_{IR}\,\alpha}=\left[\frac{ef}{(u_{II}-\alpha)^- + u_{IR}\,\alpha}\,n-\frac{\alpha}{(u_{II}-\alpha)^+ + u_{IR}\,\alpha}\right]^- \tag{14}$$

The question is whether the results in Figure 2 support model (14) which is derived from the general theoretical framework.

Effect of Anxiety Level. The actual anxiety levels corresponding to the conditions low-MAS and high-MAS are symbolized by α_1 and α_2 $(\alpha_1<\alpha_2)$, respectively. The effects of anxiety levels α_i which are predicted by model (14) can be described by the following functional relationship (15) between the odds of high-MAS and low-MAS subjects. Again equation (15) should hold under variation of the remaining variables.

$$\left(\frac{p_r}{1-p_r}\right)_2=\left[\left(\frac{p_r}{1-p_r}\right)_1\frac{(u_{II}-\alpha_1)^+ + u_{IR}\,\alpha_1}{(u_{II}-\alpha_2)^+ + u_{IR}\,\alpha_2}-\frac{(\alpha_2-\alpha_1)}{(u_{II}-\alpha_2)^+ + u_{IR}\,\alpha_2}\right]^{\cdot} \tag{15}$$

According to (15) a linear relationship with an obtuse angle at the abscissa is expected between the empirical odds. The angle arises because with increasing task relevant response tendency the high anxiety threshold (α_2) is exceeded later than the low anxiety threshold (α_1) and below threshold the corresponding recall probabilities are zero. Prediction (15) is equally valid for difficult and for easy words because the function is not dependent on the varaible e.

When the slope in (15) is one or less model (14) predicts superior performance for all experimental conditions with low anxiety as compared to high anxiety because the abscissa intercept in (15) is always positive for $\alpha_2>\alpha_1$. Figure 2 displays that in the present case the learning curves for low MAS and high MAS subjects intersect at a recall frequency of about 0.5. This holds for both easy and difficult words. Consequently, the REC-Curve for the odds must pass the point (1,1). On the premises that $\alpha_1\neq\alpha_2$ and that $u_{II}>\alpha_i$ this implies that $u_{IR}=0$ in (15). There are two possibilities to explain this consequence within the proposed theoretical framework: Either the stress situation did not elicit threat relevant response tendencies in this experiment or the threat relevant response tendencies did not compete with the task relevant response tendencies. In either case prediction (15) reduces to (16).

$$\left(\frac{p_r}{1-p_r}\right)_2=\left[\left(\frac{p_r}{1-p_r}\right)_1\frac{(u_{II}-\alpha_1)^+}{(u_{II}-\alpha_2)^+}\quad\frac{(\alpha_2-\alpha_1)}{(u_{II}-\alpha_2)^+}\right]^- \tag{16}$$

The data from Figure 2 are transformed into odds, and these are displayed in Figure 3. Prediction (16) is well confirmed by the empirical relationship between high-MAS and low-MAS odds. The slope is about 2.575 and the ordinate intercept is about -1.575. These values will be used below for estimating the ratio of the anxiety levels α_2/α_1.

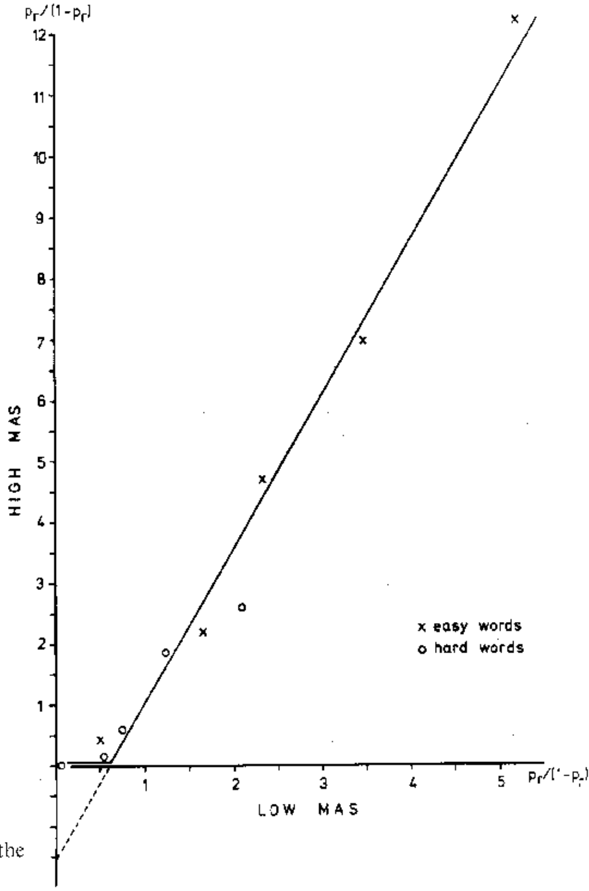

Fig. 3. REC-curve for MAS-levels for the data from Figure 2

Effect of Task Difficulty. With $u_{IR}=0$ model (14) predicts (17) for the effect of task difficulty. Here e_2 symbolizes the easiness of the easy words and e_1 that of the difficult words $(e_2>e_1)$.

$$\left(\frac{p_r}{1-p_r}\right)_2=\left(\frac{p_r}{1-p_r}\right)_1\frac{e_2}{e_1}+\left(\frac{e_2}{e_1}-1\right)\frac{\alpha}{(u_{II}-\alpha)^+} \tag{17}$$

Equation (17) is again a linear function with an obtuse angle at the ordinate since $(p_r/(1-p_r))_1$ cannot become smaller than zero. The explanation is the same as above. Because (17) depends also on the anxiety variable α different straight lines but with equal slopes are predicted for the two anxiety conditions.

Figure 4 shows that prediction (17) is confirmed sufficiently well by the data. According to (17) the slopes indicate that the easy words were about 2.5 times as easy as the difficult words. The ordinate intercepts have values of about 0.35 for low MAS and

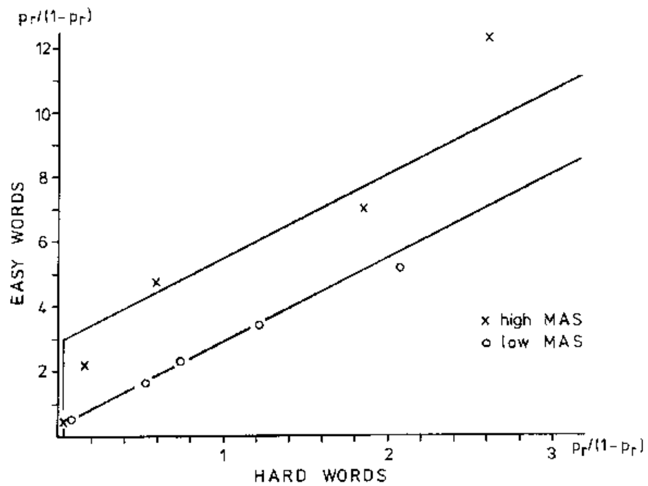

Fig. 4. REC-curves for difficulty levels for the data from Figure 2

2.9 for high MAS. Together with the previously obtained values these results allow to estimate the anxiety ratio α_2/α_1 by applying (16) and (17). A value of about 3.6 is estimated.

Effect of Learning Trials. The analysis of Spielberger and Smith's data made so far did not test the assumed linearity of the learning function since (16) and (17) are independent of the number of trial blocks n. It has merely been assumed that the same learning function caused the variation of the recall frequencies or odds in all four anxiety/difficulty conditions.

The hypothesis of an increment proportional to n is easy to verify, because according to model (14) the odds are linear functions of the trial number. Again, these functions have an angle at the abscissa, which is also explained by different levels of the anxiety threshold. According to (14) different slopes of the straight lines are expected for the four anxiety/difficulty conditions. The ordinate intercepts should differ only between anxiety conditions. Using (17) their values may be obtained from Figure 4. According to (14) the two straight lines for each difficulty condition should intersect at the point $(1, u_{II}/ef)$ for $u_{IR}=0$.

The hypothesis of a learning increment proportional to trial or block number is well confirmed by Figure 5.

To summarize, it can be concluded that Spielberger and Smith's (1966) data are compatible with model (14), as long as the required assumption of a missing or non-competing threat relevant response tendency is considered as being consistent with the theoretical framework.

Acquisition of Positional Motor Responses

Undoubtedly most of the experimental studies on the effect of anxiety on learning performance used verbal learning material. There are, however, some studies in which spatial relations had to be learned and in which motor responses were used as measures

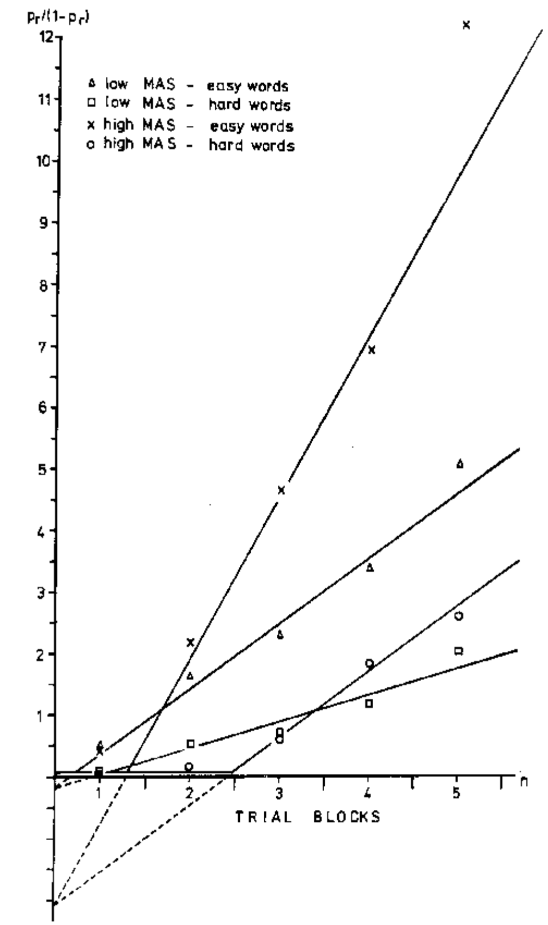

Fig. 5. 'Learning functions' for the data from Figure 2

of performance. Among others (e. g. S. B. Sarason, Mandler and Craighill, 1952, Experiment II; Matarazzo, Ulett and Saslow, 1955) the experiment performed by Castaneda and Lipsitt (1959) belongs to this group of studies.

The subjects in this experiment, children aged about 10 years, were presented eight horizontally arranged lamps beneath which eight buttons were situated. For four lamps the correct button was located directly below (dominant tendency correct), while the correct button for the other four lamps was one of the two buttons on either side of the one directly below (dominant tendency incorrect). The authors had observed that children of this age who are presented with the array and one lamp lighting up spontaneously prefer the button directly below – probably a consequence of prior experience and/or high compatibility. In each trial of the learning experiment one of the eight lamps lighted up in a balanced random order, the subject pressed one of the three allocated buttons, and feedback about the correctness was given.

The authors used a $2\times2\times4$ experimental design. Between the experimental groups (a) situational stress was varied by exerting (Stress) or not exerting (Nonstress) time pressure for responding. The two within-group variables were: (b) task difficulty, which was varied in the described manner by using tasks for which the dominant tendency was either correct (DTC) or incorrect (DTI); (c) learning trials, which were divided into four blocks of 20 trials each. Each block consisted of 10 DTC-tasks and 10 DTI-tasks. The dependent variable was the percentage of correct responses. Responses of the subjects in the stress group which were given after the time limit were also counted for the percentage scores. But in these cases no correctness feedback was given. The results of this experiment are shown in Figure 6.

The theoretical analysis of this study is similar to the preceeding analysis of Spielberger and Smith's results except for the following changes. Instead of varying anxiousness situational stress was manipulated in this study. Thus, it has to be presupposed that the subjects were anxious with respect to the particular stress condition, i.e. $a>0$ in (4), in order to be able to postulate a variation of the actual anxiety level in (13). Model (14) needs two modifications. Preexperimental experiences, compatibilities, and guessing possibilities cause probabilities of correct answering prior to experimental learning that are higher than zero. According to (6) these preexperimental task relevant response tendencies are represented by $fn_0>0$. Moreover, Figure 6 shows that competing threat relevant, task irrelevant tendencies seem to have been absent. Again the assumption $u_{IR}=0$ is made.

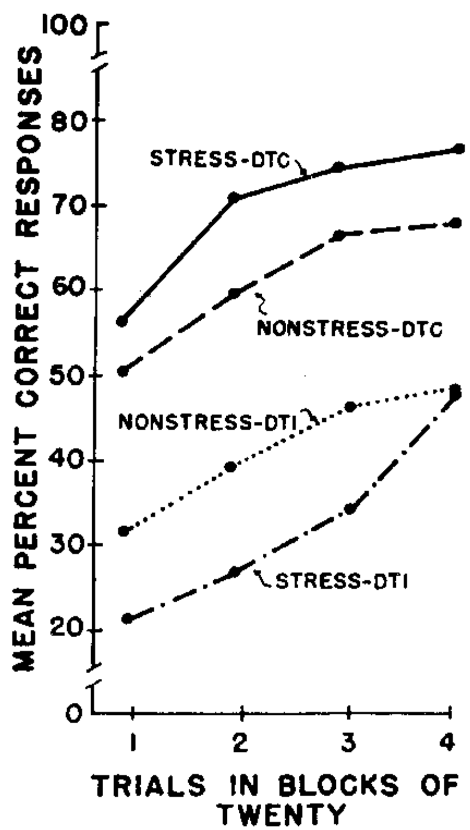

Fig. 6. Results of Castaneda and Lipsitt's (1959) experiment on positional motor learning (Figure taken from Castaneda and Lipsitt (1959), with kind permission)

Accordingly, the special model (18) is derived from (13) for analysing these data.

$$\frac{p_r}{1-p_r}=\frac{[ef(n+n_0)-\alpha]^+}{(u_{II}-\alpha)^+}=\left[\frac{ef}{(u_{II}-\alpha)^+}n+\frac{efn_0-\alpha}{(u_{II}-\alpha)^+}\right]^+ \tag{18}$$

Effect of Anxiety Level. For the effect of the anxiety level α the previous prediction (16) is also obtained for the special case of model (18). The data presented in Figure 7 agree well with this prediction. The slope has a value of about 2.22 and the ordinate intercept is located at about -1.19.

Effect of Task Difficulty. For the effect of the task difficulty $1/e$ or its easiness e, respectively, prediction (17) is obtained from model (18).

For the nonstress condition a good agreement of the data with prediction (17) is displayed in Figure 8. For the stress condition, however, the agreement is questionable. If (17) is accepted for the data the slopes indicate that the DTC-tasks are about 2.2 times as easy as the DTI-tasks. The ordinate intercepts have values of about 1.42 for the stress

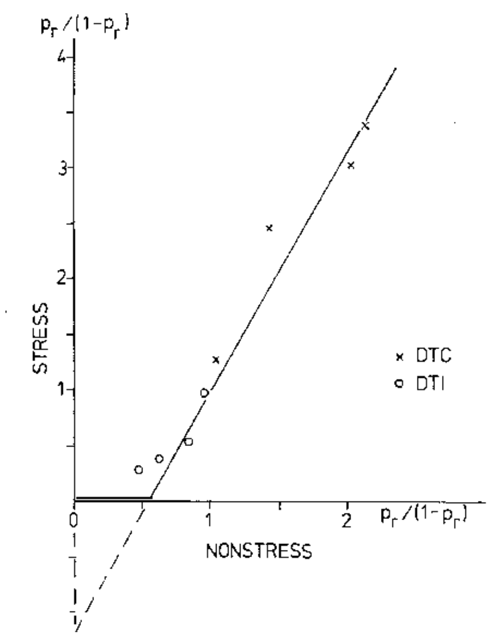

Fig. 7. REC-curve for stress conditions for the data from Figure 6

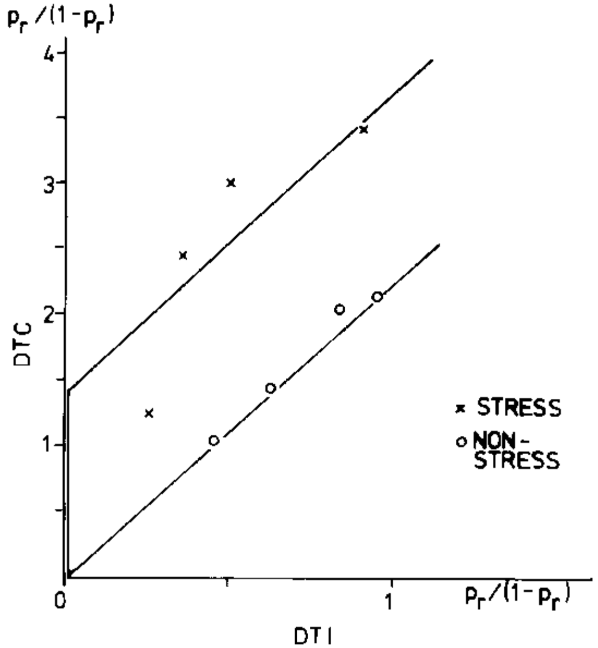

Fig. 8. REC-curves for difficulty levels for the data from Figure 6

condition and about 0.0 for the nonstress condition. The last datum indicates that, according to (17), the nonstress group was anxiety-free with $\alpha_l = 0$. Thus the ratio of anxiety levels is undefined.

Effect of Learning Trials. Figure 9 serves to examine the hypothesis of a linear learning function, which is included in model (18). Again the hypothesis appears to be well supported for the nonstress condition. The less good fit of the stress data needs discussion.

The predictions of model (18) are only partly corroborated by Castaneda and Lipsitt's (1959) data on the acquisition of positional motor responses. The deviations can probably be explained by the lack of correspondence between the feedback procedures of the experiment and the learning assumptions of the theoretical framework. As mentioned above, only correctness feedback was given, and even this was missing in the stress group when the time limit was exceeded. With three response alternatives the amount of feedback-information consequently depends on the correctness and in the stress group additionally on the speed of responding. According to the model the learning function is assumed to be the same for all difficulty/stress conditions and should depend only on the trial number. Contrarily, the feedback procedure in this experiment was such that learning depended also on the other variables determining the response probability. Thus the observed deviations do not necessarily contradict the theoretical framework.

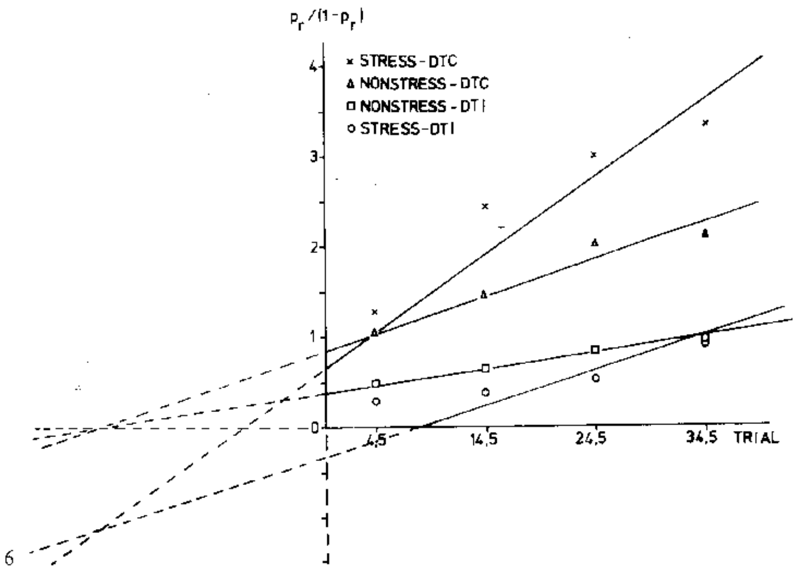

Fig. 9. 'Learning functions' for the data from Figure 6

Discussion

The present theoretical approach again, after Spence (1956), tries to explain the effect of anxiety on learning performance by an extensive and formalised framework. The framework is extensive in so far as (a) a differential effect of anxiety is postulated by assumptions (2) and (3) in order to account for (b) different effects of anxiety in different types of learning tasks and (c) the effects of several other variables determining performance are described in the model.

About the Empirical Evidence

The formalisation of the theoretical framework allowed empirical tests of quantitative predictions of a precision as has been achieved before in the field of anxiety-performance-research only by Grice (1968, 1971, 1972). For reasons of dispensing with statistical procedures for estimation and model testing the advantages of the formalisation are certainly not exhausted.

Although the empirical tests presented above were primarily exemplary they, nevertheless, should be able to indicate whether further investigation of the theoretical approach is worthwhile. In connection with this question the following points should be considered:

(a) The presented theoretical framework was only partly tested: The effect of the variable "learning ability" (equation 5.2) could not be examined at all with the present data; the studies on the acquisition of verbal and motor responses did not allow to examine the effect of the variable "stimulus relevance" (5.2) and the postulated combined effect of anxiousness and stress (4).

(b) The theoretical framework refers to the behaviour of individuals with individual differences being represented by different parameter values for the person-related variables (learning ability, anxiousness). However, only group data were available for examination so that it had to be assumed that the subjects in a whole experiment or at least in an experimental group had equal learning ability with respect to the type of task and equal anxiousness with respect to the type of stress situation. These assumptions are certainly incorrect. It may be easily shown that neglected individual differences can not simply be "averaged out", but that they lead to deviations from the model predictions.

(c) The variables representing the situational effects can be considered to be constant for the situational conditions because each of them was experimentally produced and manipulated. However, even in this case summarizing several levels (such as tasks or trials) may yield deviations from the model predictions. This may be illustrated by summarizing trials. The probability of a correct response is zero prior to that trial in which the threat irrelevant and task relevant tendency exceeds the anxiety threshold; after that trial it becomes positive. Averaging over this range and assigning the obtained value to the mean trial will result in a deviation from the predicted value. The systematic deviations in the region of the predicted angles which appeared in some figures may be due to such inappropriate averaging.

With the restrictions noted in (a) and under consideration of the pooling for persons (b) and situations (c) the models derived from the general framework agree quite well with the data. According to this criterion the theoretical framework appears promising and further investigations should be worthwhile.

Relationship to other Theories

As mentioned in the beginning, the present framework incorporates some approved assumptions from other theories which were only partly referred to. In the following I will try to further clarify the congruencies and differences to other theories.

In view of the initial aim it is justifiable to begin with the relationship to drive theory despite its seemingly low relevance to actual anxiety-performance-research, apart from studies on so-called social activation. This comparison with drive theory is already justified by the fact that in a large range both theories predict similar effects, at least in direction. Actually, it was suspected that both theories could be formally equivalent using the same distributional assumptions and considering the same number of corresponding variables. Albert (1977 a), however, could refute this argument.

The first advantage of the present proposal over drive theory is that it is mathematically much simpler, which makes it more easily testable; for a comparison, see e. g. the effort to derive quantitative predictions from drive theory in Spence (1956, Appendix). The simplicity of the present approach also allows to incorporate formally later developments of drive theory which have only been presented verbally by their advocates. These are the task irrelevant anxiety reaction of Spence and Spence (1966) and the dependence of actual anxiety on person-related and situation-related variables of Spielberger (1966, 1972, 1975) and co-workers. However, these further developments can also be easily formalized within the framework of a slightly modified drive theory as Albert (in press) shows.

Furthermore, the present framework is more economical since it needs one variable less. Matching the variables of the two concepts to one another according to the experimental manipulation represented by them makes apparent that the reaction threshold in drive theory has no counterpart in the present framework. The function of the reaction threshold in drive theory is to explain the absence of a response in so-called "simple tasks" having only one reaction potential, as it is, for instance, assumed for the conditioned cyelid response. For the sake of consistency a reaction threshold has been assumed also for so-called "complex tasks" having competing reaction potentials. This makes drive theory among other things "unwieldy". Within the present framework the assumption of such a threshold is not needed since task irrelevant, competing tendencies are postulated for every type of task.

However, the greater economy with respect to the number of necessary variables is compensated by the assumption of two anxiety effects according to (2) and (3). Assumption (2) resembles the multiplicative connection of "drive" and "habit" – but it is different. On the basis of the "behaviour ratio assumption" and with the omission of the reaction threshold the "drive × habit-assumption" becomes $v_{..} = u^{\delta}_{..}$, where δ represents the drive (Albert, 1976 b). Assumption (2) rather corresponds to considerations of Mandler and Sarason (1952) which were also taken over by drive theory (Spence and Spence, 1966) – see below.

In my opinion the main advantage of the present approach as compared to drive theory is seen when its possible explanatory range is extended beyond the predictions considered above. Since Yerkes and Dodson (1908) an inverse U-shaped relationship between performance and anxiety level has often been postulated and is empirically supported at least in discrimination tasks. Moreover, according to the Yerkes-Dodson-Law the optimal anxiety level is considered to be lower for difficult than for easy tasks.

Drive theory can also explain this phenomenon with the help of additional assumptions. Spence (1956, 1958) assumed "that under an increased drive more responses will become superthreshold and thus likely, because of oscillation, to provide more competing responses" (Spence, 1956, p. 222). Broen and Storms (1961, 1967) make the assumption of an upper limit for the strength of the reaction potentials in order to give a more precisely formulated explanation within drive theory. Initially an increased drive will lead to an increase in the probability of a dominant relavant response tendency becoming effective; upon reaching the upper limit for the dominant tendency, however, only the non-dominant irrelevant response tendencies will be increased by increasing drive resulting in a decrease of the response probability. Contrarily to the Yerkes-Dodson-Law an U-shaped relationship should result for irrelevant responses beeing dominant.

The present framework provides an explanation for the "Law" and a restriction of its validity range without any additional assumptions. For model (7) an increasing anxiety level will always result in increasing performance. For model (13) the expected inverse U-shaped relationship follows only for $0 \leq u_{IR} < 1$ and $u_{RI} > u_{II}/(1 - u_{IR})$, i.e. when the task irrelevant, threat relevant tendency is low and the task is easy or well learned. In all other cases an inverse U-function does not follow from (13) but rather a decrement in performance with increasing anxiety. (A more elaborated description of these predictions, together with empirical support will be presented elsewhere.)

As an alternative to drive theory for simple tasks Grice (1968, 1971, 1972) developed a formal theory and presented an impressive amount of supporting eyelid conditioning data. His fundamental assumption about the effect of anxiety is a decrease in a normally distributed response threshold with increasing anxiety level. This increases the probability of an association being superthreshold and thus the probability of the to be learned response. Besides the mean also the variance of the threshold distribution may be affected by anxiety. With a logistically distibuted threshold Grice's and my main assumptions would be formally equivalent for classical conditioning with aversive stimulation. The change of the threshold mean and variance with anxiety in Grice's theory corresponds to my assumptions (3) and (2) respectively.

From this and from the similarity of the normal and the logistic distribution it follows that the empirical evidence presented by Grice in supporting his main theoretical assumptions also supports the present framework in so far as it relates to aversive classical conditioning. Over and above this it is applicable to other anxiety and learning situations and could therefore be considered as a generalization of Grice's theory.

Simultaneously with drive theory the first version of the competing theory of "test anxiety" was developed (Mandler and Sarason, 1952; Sarason and Mandler, 1952; Sarason, Mandler and Craighill, 1952; I. G. Sarason, 1958, 1961). Mandler and Sarason (1952) postulated three kinds of responses in a performance situation: (a) Relevant task responses R_t are evoked by the performance requirement. (b) Because of "achievement anxiety" task relevant anxiety responses R_{at} are learned for task completion. (c) Task irrelevant anxiety responses R_a belonging to the response repertoire because of earlier experiences in performance situations are evoked for coping with anxiety and interfere with task completion, i. e. with the responses R_t and R_{at}, thus diminishing performance. This type of anxiety responses R_a has been incorporated later by Spence and Spence (1966) into drive theory.

An increase or decrease in performance relative to control conditions results depending on whether the task relevant or the task irrelevant anxiety response dominates. Child (1954) distinguishes tasks according to the susceptibility of task relevant responses to interference. A conditioned eyelid response, for instance, is hardly susceptible to interference — anxiety increases performance because of R_{at}. A paired associate response, however, is strongly susceptible to interference — anxiety rather decreases performance because of R_a. I. G. Sarason (e. g. 1958) assumes that higher test anxiety and as a consequence more interfering responses are evoked by complex, difficult tasks. The authors with this theoretical reasoning commonly assume that performance decreasing anxiety responses exceed performance increasing anxiety responses for subjects with high test anxiety (determined by special questionnaires, e. g. Sarason and Mandler, 1952) performing complex, difficult tasks in egoinvolving situations.

The theory seems, however, to be formulated not precisely enough to allow differentiated predictions; thus it also provides no explanation for the Yerkes-Dodson-Law because the dependence of performance increasing and performance decreasing anxiety responses on anxiety level and other variables is not precisely formulated.

The response types of the test-anxiety theory are similar to those of the present framework (Table 1). Apparently the following assignments can be made: $R_a \sim IR$, $R_t \sim RI$, $R_{at} \sim RR$. The first two equivalences are indeed correct, but the third is not. According to test-anxiety theory responses of type R_{at} arise during task completion in every performance situation. According to the present framework responses of the type RR exist pre-experimentally and belong to the threat relevant repertoire just as the responses of type $IR \sim R_a$. They may even be identical to these. It depends on the task whether a response from the repertoire belongs to type RR or IR. Moreover, there is no analogue to type II responses in test-anxiety theory.

Common to both theoretical frameworks is the increase or strengthening of task irrelevant anxiety responses ($IR \sim R_a$) with increasing anxiety level. Equation (2) of the present framework provides, however, a more general, more precise, and more easily disprovable formulation of this assumption. The extent to which a falsity is already approached by equating $u_{IR}=0$ (which was appropriate for the data of the last two experiments evaluated above) can not be decided before data from experiments with a general superiority of performance for low anxiety levels have been evaluated and before more is known about the reasons for the divergent results.

Test-anxiety theory has been reinterpreted during the last ten years by Wine (1971) and I. G. Sarason (e. g. 1972, 1975). According to these reinterpretations the direction of attention is guided by test-anxiety. Test-anxiety has two consequences, (a) attention is directed towards environmental cues promising help, which may aid performance, and (b) attention is directed towards the subject himself, which decreases performance since attention is withdrawn from task completion.

The earlier approach of Easterbrook (1959) is attention oriented too. The range of attention or, in other words, the range of cue utilization is assumed to be dependent on the emotional level, in this case, the anxiety level of the individual. A higher emotional level leads to a smaller range of attention. In simple tasks, where task completion requires only processing of a few cues simultaneously, irrelevant cues may be excluded by a limited range of attention which will result in a performance increment. In complex tasks requiring the simultaneous processing of many cues for completion the restriction of attention range leads to an exclusion of relevant cues already at a low emotional level which results in a performance decrement. But a higher emotional levels performance may also decrease in simple tasks if the relevant cues were also affected by a large restriction of the attention range. Here Easterbrook presents a plausible explanation of the Yerkes-Dodson-Law. According to Easterbrook learning either decreases the number of irrelevant cues or increases the number of relevant cues.

The present framework seems to be fundamentally different from the attention oriented approach. It localizes the operation of anxiety in response processing whereas the attention oriented approach localizes it in stimulus processing. Nevertheless, the question of the relation between the different frameworks will be pursued by an attempt of reinterpreting the present approach. The formal representation of a theoretical approach has also the advantage of being easily reinterpretable since semantic and symbolic levels are clearly separated.

Assuming that the responses are directly dependent on the effective stimuli or cues, as, for instance, in Estes' (e. g. 1950) stimulus sampling theory, equation (3) can be interpretated as a reduction of attention range caused by anxiety and restricted to threat irrelevant stimuli. Equation (2) can be understood as an anxiety dependent concentration or focussing of attention to threat relevant stimuli. Equations (5.1) and

(5.2) would be interpreted by increasing the utilization of the task relevant stimuli during learning. Response probability depends on the ratio of utilized task relevant and task irrelevant stimuli. How does an inverse U-shaped relation between the response probability and the anxiety level arise? Assume an easy or well learned task with task relevant, threat irrelevant stimuli exceeding the task irrelevant, threat irrelevant stimuli and a situation with only few threat relevant stimuli in it. Then the effectiveness of the task relevant stimuli will initially profit from a reduction of the attention range (3) since they are less strongly affected in comparison to the task irrelevant stimuli. A further reduction of the attention range would, however, affect the task relevant stimuli – the task irrelevant stimuli are already eliminated – to such an extent that performance decreases again.

It may be unsatisfactory that the formal framework allows two very different interpretations, especially since the question whether "input" or "output" processes are involved is of some importance in current cognitive psychology. The history of modern psychology, however, shows that there has been a series of contrary viewpoints which could not (yet) be distinguished on empirical grounds. In the presence of competing formal frameworks filtering out the one which best describes the empirical findings before tracing the question of its "final" interpretation seems to be a reasonable strategy. In the light of this argument too, the present formal framework has to be subjected – in competition with other formal frameworks – to further experimental examination.

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