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Abstract	Yerkes and Donson formulated a relationship between arousal and task difficulty in 1908, and the formulation is wellknown under the name of Yerkes-Dodson law, and still today often referred to and commented on in articles of psychology and educational psychology. The authors reviewed several articles in Which the law was commented on. After examining the original experiment conducted by Yerkes and Dodson from where the law was established, the authors introduced Biggs' cognitive model as the most lucid and cogent theorizing of the law. The authors proposed three conditions to be met if the model works well to explain the underlying processes of the law. Several experimental evidences that might support the law were cited from previous researches, and that could not positively prove the theorizing from authors' own experimental data. Finally, the implication of the theorizing of Yerkes-Dodson law was discussed in a broader framework of Aptitude-Treatment Interaction.
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Yerkes-Dodson law revisited: The implication of the age-old law in the light of a cognitive theorizing*

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Yerkes and Dodson formulated a relationship between arousal and task difficulty in 1908, and the formulation is wellknown under the name of Yerkes-Dodson law, and still today often referred to and commented on in articles of psychology and educational psychology. The authors reviewed several articles in which the law was commented on. After examining the original experiment conducted by Yerkes and Dodson from where the law was established, the authors introduced Biggs' cognitive model as the most lucid and cogent theorizing of the law. The authors proposed three conditions to be met if the model works well to explain the underlying processes of the law. Several experimental evidences that might support the law were cited from previous researches, and that could not positively prove the theorizing from authors' own experimental data. Finally, the implication of the theorizing of Yerkes-Dodson law was discussed in a broader framework of Aptitude-Treatment Interaction.

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Anxiety and learning

Besides intelligence, anxiety has long been acknowledged as one of the strongest restricting variables on learning, especially on school learning. Anxiety functions often in a complicated, rather paradoxical manner, sometimes as a fascilitating factor, sometimes as a deteriorating factor, depending on the age and personality of a learner, the kind and difficulty of a learning task, and many unidentified contextual factors. General intelligence, in contrast to anxiety, usually contributes to learning in the form of monotonously increasing function.

As regards the complicated effects of anxiety on learning, a formulation under the name of Yearkes-Dodson law is wellknown, and it reads as follows: "While performance on an easy discrimination task improved with increasing shock intensy, performance on a difficult task was worse with weak and strong, and optimal with intermediate level shocks" (Mandler, 1979). The detailed description of their experiment, from where the law was obtained, will be given in the next section.

Hockey (1979) expressed this law in modern terms as two separate postulations:

(a) For any task there is an optimal level of arousal such that performance is related to arousal in the form of an inverted U.

(b) The optimal levels of arousal is a decreasing monotonic function of the difficulty of the task.

It is problematic to simply equate anxiety with arousal, but in this article we decided not to discuss this point any further, and treat these two constructs interchangeably. This formulation, therefore, should be generalized to anxiety as well.

Yerkes-Dodson law was proposed at the beginning of this century, and is still today so often referred to, and commented on, as to make Mandler (1979) write "a surprisingly robust law given the poor track record of psychological generalization over the years." Here mention will be made on only a few of references to the law.

Hockey (1979) wrote, after expressing this law as mentioned above, and redrawing the original figure written by Yerkes and Dodson themselves (See Fig. 1):

> There is considerable support for these claims, both from work in animal learning itself, and from research in human learning and performance. There is also an intuitive appeal about the proposed form of this relationship in terms of personal experience…… These observations are persuasive and are, I think, the acceptance of the Yerkes-Dodson law in human stress research. I do not want to object to its failure to describe the effects of stress adequately, but it blinds us to the recognition of more fundamental changes in functioning (Hockey, 1979, p. 143).

He devoted the whole chapter entitled "Stress and the cognitive components of skilled performance" to the examination of the law, and wrote that he would address himself to "What changes underly the observations embodied in Yerkes-Dodson law?", "Why are high levels of arousal bad for performance?", and "What makes a task difficult?". These questions must be answered if the law has significance as a well-formulated law even in the advanced stage of today's psychology.

Entwistle discussed the relationship between personality and academic attainment, and made reference to the law as follows:

> The effect of neuroticism is less easy to predict. It has been argued from the "Yerkes-Dodson law" that there might be an inverted U relationship between academic performance and neuroticism. In the original Yerkes-Dodson experiments on mice, intermediate level of drive (hunger) led to higher level of performance (maze running) for tasks of moderate difficulty. Anxiety is commonly seen as equivalent spur to human behavior, and it seemed reasonable that too much anxiety, or too little, might inhibit classroom attainment (Entwistle, 1981, p. 189).

By the way, it is strange that, in the original experiment done by Yerkes and Dodson, arousal level was manipulated with level of electric shock, and not with hunger. To be exact we would like to introduce the original experiment in the next section from the article published in 1908.

Entwistle also commented on several studies which seemed to be in line with prediction by the law, and two largest British studies on school children not in line with it. One of them was done by himself, and a linear negative relationship between neuroticism score and school marks was obtained. In the other experiment done by other researchers, the relationship was U-shaped, quite contrary to the prediction, with both high and law score on neuroticism obtaining high outcome (Entwistle, 1981).

Jensen introduced a theory to the effect that general intelligence results from individual differences in will, motivation, or drive level. He criticized this theory in relation to Yerkes-Dodson law and wrote as follows:

> A theory of *g* as D (Hull's D) runs into trouble with the Yerkes-Dodson law. The empirical generalization that the optimal drive level for error-free of efficient performance of a task is lower for simple than for complex tasks. Yet cognitively complex tasks are generally more *g* loaded than simple tasks, and high- and low-*g* individuals differ more on complex than on simple tasks. We should predicts just the opposite if *g* were equated with D (Jensen, 1987, p. 121).

As stated above, intelligence is usually related to performance in monotonic increasing function, and it is impossible that the optimal point for a easier task is located on a higher position on *g* dimension than a more difficult task if *g* runs parallel with arousal.

Finally we would like to make a point that especially from our research interest theorizing of the law is badly needed. We have been engaged in Aptitude-Treatment Interaction research for nearly two decades, and making an effort to treat two aptitude dimensions simultaneously. If optimization of instructional methods could be made possible in terms of this type of ATI, adaptation of educational environment to individuality would be much more perfect (Namiki and Hayashi, 1977). We selected intelligence and anxiety as two aptitudes based on previous researches. However, this selection was done atheoretically because any suitable model in which these two constructs could be integrated theoretically was not available yet. As Snow (1989) recently discussed conative and affective aptitude processes in his extensive review of ATI research, here again referring to Yerkes-Dodson law, he argued strongly for an integration of cognitive, conative and affective research on aptitude for learning. For this integration, a plausible and valid theorizing of Yerkes-Dodson law will surely be a cornerstone to the next advancement of psychology of aptitude and learning. And, a cognitive model offered by Biggs (1981) must be the long-expected one as will be discussed in details in later section.

Yerkes and Dodson's experiment

The inverted U-shape relationship of learning performance against arousal level is known as Yerkes-Dodson law, after the names of the researchers, R. M. Yerkes and J. D. Dodson, who demonstrated this relationship for the first time. In order to know the law in its original form, we will briefly introduce their work entitled "*The relation of strength of stimulus to rapidity of habit-formation*" which appeared in *Journal of Comparative Neurology and Psychology* in 1908.

The experimental paradigm was a typical avoidance conditioning in terms of visual discrimination task, with dancing mice as subjects. The purpose was to clarify the relation of strength of stimulus to rate of discrimination habit formation as a function of task difficulty. The mice were required to choose and enter one of two boxes, one of which was white and the other black. Choosing the white box was defined as correct response, and if they entered the black one they received a disagreeable electric shock.

In this black-white discrimination task, dependent variable was the number of trials before subjects perfectly acquired the habit. The criteria of perfect acquisition was defined as three successive correct responses. There were two independent variables: task difficulty and strength of electric stimulus (arousal or stress level). The first factor contained three levels of task difficulty, easy, medium, and difficult, and was manipulated in terms of brightness of boxes: increase of brightness reduced task difficulty because white-black contrast became obvious and vice versa. As for the second factor, the number of stimulus strength levels differed among levels of task difficulty. There were five levels of stimulus strength in easy condition and four levels in difficult condition, and only three in the medium condition. In other words, these two experimental factors were not completely crossed. Though sex was controlled, the number of subjects were small (only two or four) and also different between cells. Because such statistical methods and experimental design as ANOVA were not known in those days, the experimental procedure was thus ill-controlled from today's standard of psychological experiment. The analysis was purely descriptive and any method of statistical test was not used.

Although the analysis of data was not sophisticated, the results were clear and impressive. The main result is depicted in Fig. 1. This figure was redrawn by Hockey from the original one. In the original figure, ordinate represented number of trials, but Hockey reversed the direction of ordinate to obtain the optimal point of performance on the inverted U-shape. The figure shows that the relation between stress and learning rate is not linear, but curvilinear, and has an optimal point, and that the optimal point shifts to the higher position on abscissa as the difficulty level gets lower. As for the easy task, the potimal point is not clear, maybe because of a ceiling effect, or restriction of intensity level

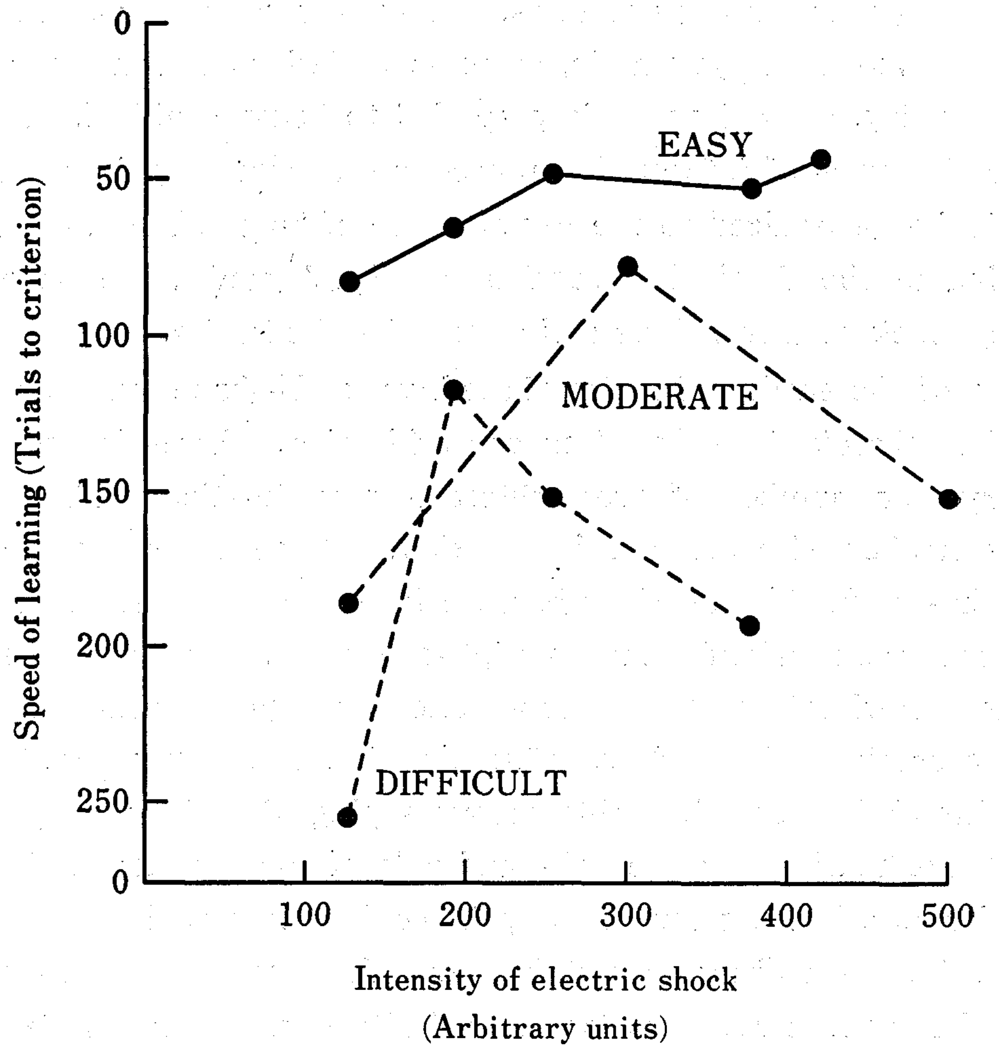

Fig. 1 The relation between drive level and learning. (Redrawn from Yerkes and Dodson's original figure by Hockey, 1979)

due to safety. In this article the authors did not give any explanation or hypothesis about the psychological and physiological mechanism underlying this phenomenon.

Preceeding theories and Biggs' model in terms of working memory

Yerkes-Dodson law is purely descriptive rather than explanatory, as already pointed out by, for example, Hamilton (1979). According to him, the law cannot specify cognitive as distinct from physiological mediating processes, and for ethical reasons, has not been derived from systematic, extreme variations of either general emotionality, arousal or anxiety applied to human subject. Theorizing in terms of information processing is necessary if the law should be generalized to the performance of human being. Before turning to the detailed discussion of Biggs' model, we have to have a look at a few forerunning or related theories.

One of the earliest theories of the inverted U-shape was proposed by Easterbrook (1959) based on cue utilization. According to this theory, the number of cues utilized in any situation tends to become smaller with increase in emotion. When tasks are simple this has a fascilitatig effect because irrelevant cues are excluded. On the more difficult and multiple-cue tasks, the same change causes deteriorating effect because relevant cues are also excluded (Easterbrook, 1959; Hockey, 1979; Mandler, 1979; Hamilton, 1979). Hamilton (1979) criticized this theory saying that it may give a good explanation for the left-hand side of the inverted U-shaped relationship, but not for the drop in performance with high levels of strain. In addition, a certain mechanism, perhaps ameta-cognitive function, must work on the priority given to cue utilization between relevant informaton and irrelevant information, and we are doubtful how it is possible.

Näätänen (1975) theorized in terms of a reduction in attention to a task. According to him, the relation between stress and efficiency is monotonic until an optimal point, and above this point drop of performance occurs due to a reduction in attention to the task. And this reduction results from distraction brought about by the attention demand of the activation procedure, from induced anxiety or other cognitive reactions to the stress (Hockey, 1979). This theory might explain well the inverted U-shape, but no direct explanation is given about the shift of the optimal point depending on task difficulty. We make mention on this theory because its key concept, attention, is closely related to working memory on which Biggs' theory is founded.

The next theory, Hamilton's (1979), on neurotic anxiety is based on working memory, and has direct relationship to Biggs' model. As for successful task performance in problem solving, the following formulation was suggested by him:

$$APC + SPC > I_{e(P)} + I_{i(C)} + I_{i(A)}$$

where APC is average processing capacity, SPC is spare processing capacity, $I_{e(P)}$ is externally presented primary task information, $I_{i(C)}$ is internally generated, task-relevant, competing information, and where $I_{i(A)}$ indicates the level of internally generated aversive information, i.e. anxiety. If the left hand side of the above formulation is larger than the right hand side, the performance is successful because working memory capacity is sufficient enough to process given amount of information properly. Hamilton said that the formulation was consistent with his own experimental data on anxiety and neurotic anxiety.

Here let us turn to the details of Biggs' theorizing. Relationship between arousal and task complexity is depicted in Fig. 2 by Biggs, and this is a theoretical expression of Yerkes-Dodson law. In this figure energizing or fascilitating effect of arousal accounts for the upward slope of the curves, and the interfering or deteriorating effect for the downward slope, and optimal arousal level is lower for a complex task than that of a simple task. Biggs proposed a model which explains the law depicted in Fig. 2 in terms of working memory. According to his theory, information from outer world enter our brain via two routes after passing through sensory register. One route directly reaches working memory; the other via Reticular Arousal System or RAS to working memory as depicted in Fig. 3. For example, when we become increasingly anxious, we become aware of the physiological and psychological change caused by arousal. This change is brought about by the

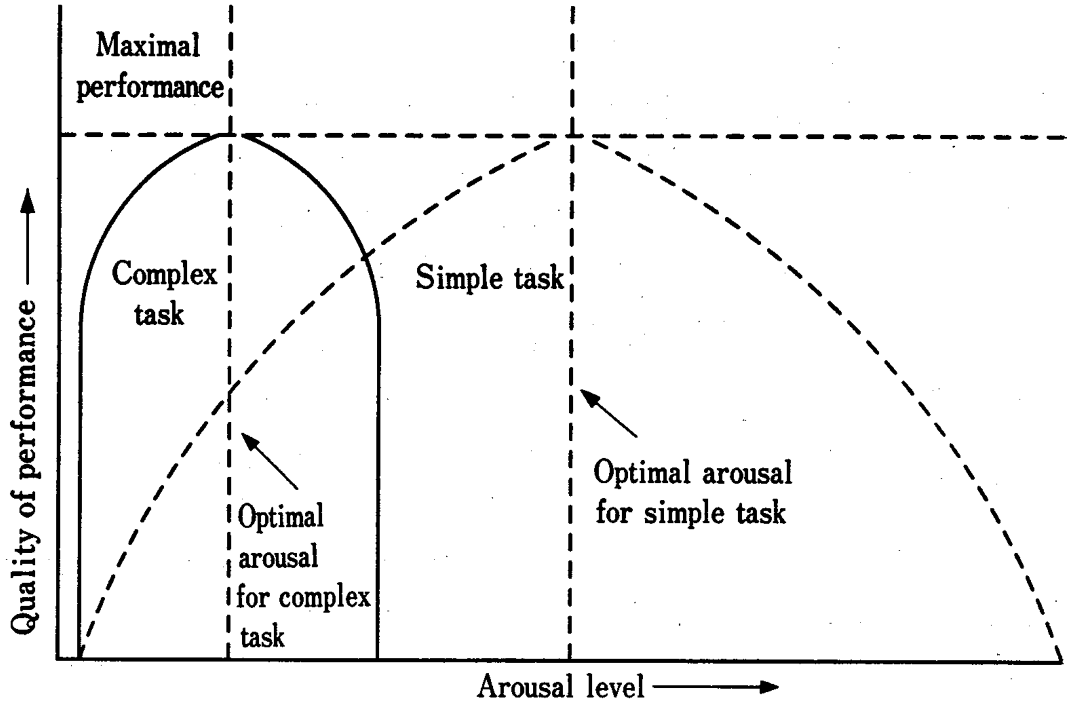

Fig. 2 Relationships between arousal and task complexity. (Biggs and Telfer, 1981)

latter piece of information, and it energizes cortical processes in general. At the same time, the awareness caused by the change occupies part of working memory capacity. This piece of information is by nature irrelevant to the information processing of a given task, it is therefore called irrelevant information (*ii*). To perform a task, information relevant to it has to be properly processed, and the number of pieces or chunks of relevant information (*ri*) is usually larger for a complex task than a simple one. To be exact we cite his words:

> These general-I-feel-awful cues simply take over working memory, to the exclusion of information relevant to the task. However, because complex tasks require more relevant cues for adequate processing than do simple tasks, such cues will be displaced earlier when performing a complex task than will be the case with simple tasks. The performer in a complex task will in effect be operating with reduced working memory, which he cannot afford to do—hence performance suffers. In simple tasks, on the other hand, reduction of the space will not matter so much and thus energizing (improvement) will continue for longer (Biggs, 1981).

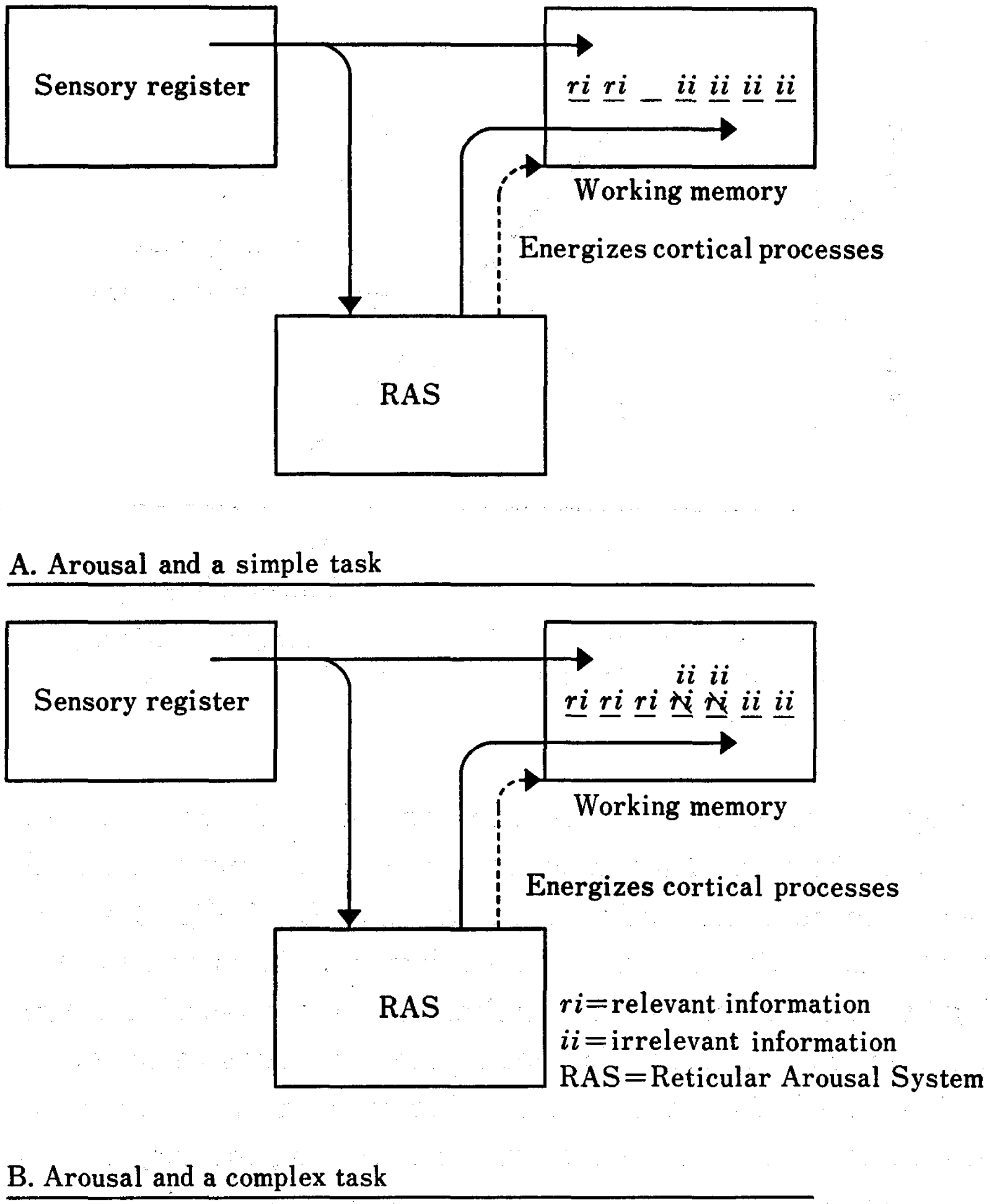

Fig. 3 Arousal and complex and simple tasks. (Redrawn from Biggs and Telfer, 1981)

In A of Fig. 3 a simple task is represented. In this case, task demand of information is two chunks (two *ri*s). It is assumed here that working memory capacity equals seven as is often the case with a normal adult. If the individual feels a certain level of anxiety and this generates four units of *ii*, and then two *ri*s and

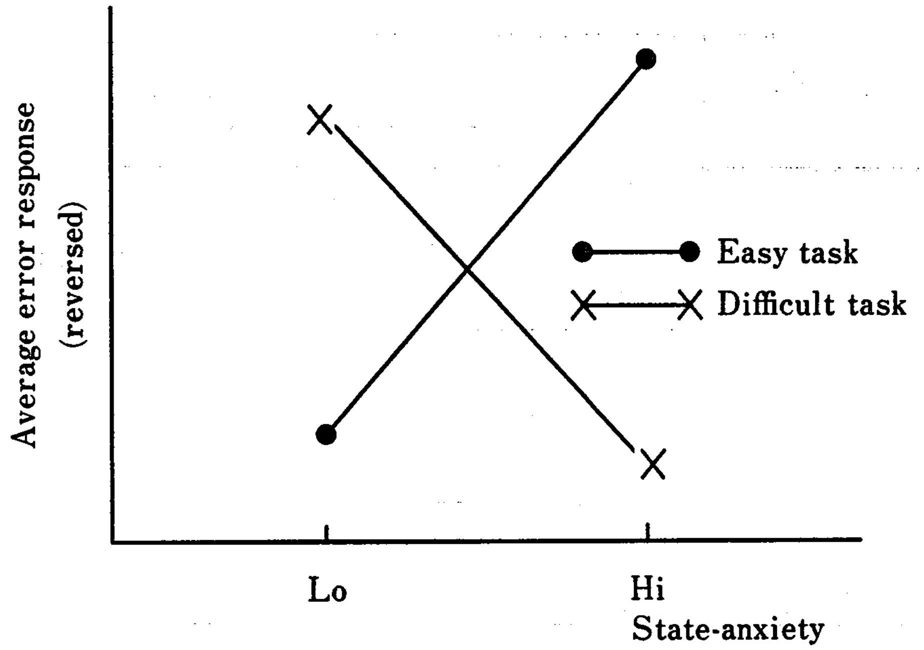

Fig. 4 The relation between level of state-anxiety and difficulty of concept acquisition tasks. (Adapted from Tennyson and Woolley, 1971)

and four *ii*s take up six units, and one unit still remains. As a result, in the case of a simple task, arousal has only a fascilitating effect with no deteriorating effect at all. B of Fig. 3 shows a complex task with five bits of task demand. In this case overlapping between *ri*s and *ii*s in the limited capacity of working memory occurs so long as arousal is kept at the same level as in A. Accordingly the individual cannot afford to perform adequately because the task demand surpasses the available working memory capacity, and deterioration results from the same level of anxiety. Biggs' model is, in our opinion, so lucid in every respect, and nothing ambiguous is left in this theorizing. We appreciate it as the most exhaustive and plausible theory ever offered until today. Thus the soundness of this theory solely depends on the validity and usefulness of the construct of working memory on which this theory is based. The concept is comparatively well-defined and operationalized among many newly offered concepts in today's cognitive psychology. We find, however, some difficulties in verifying this concept experimentally as a few authors have also pointed out (Flavell, 1978; Namiki, 1982). And the difficulties are threefold. First, the concept of working memory is not so sound from the traditional viewpoint of psychometrics although it has got popularity in today's psychology. Second, chunking of information so often and easily occurs, and accordingly accurate measurement of working memory capacity is in fact very difficult. Third, calculation of working memory demand necessary to perform a task successfully as has been done by Case (1985; Kawata, et al., 1979; Fujitani and Namiki, 1982), tends to be arbitrary, and often lacks in inter-researcher agreement (Namiki, 1982).

Notwithstanding these difficulties, the concept of working memory is so ubiquitous in our research areas. At the close of this section, we would like to quote Baddeley's concluding remarks in the epilogue of his voluminous book entitled *Working memory*:

> Hence, while it is important not to exaggerate what has been achieved, I believe that the concept of working memory has served us well. For a decade it has provided a coherent framework for exploring the role of human memory in many aspects of cognition both within the laboratory and in the world outside. Both the general concept and the specific model of working memory show every sign of continuing to be fruitful (Baddeley, 1986, p. 259).

Verification of the theory

To verify the validity of Biggs' model as a whole including Yerkes-Dodson law, at least three separate conditions have to be satisfied:

1. As for a given task at a certain difficulty level, regression line of performance onto anxiety should be curvilinear and inverted U-shaped.
2. Disordinal interaction between anxiety level and task difficulty should be obtained as an approximation to the crossover be-

tween two inverted U-shapes in Fig. 2.

3. Multiple correlation obtained among the following three variables should be substantially high: two independent variables, the number of spaces in working memory occupied by relevant information and the number of those by irrelevant information, and working memory capacity as a dependent variable. Let us define the following multiple regression equation:

$$Y_m = b_1X_r + b_2X_a + b_3$$

where X_r is a measure of the number of working memory spaces occupied by *ri*, X_a those by *ii*, b_1, b_2, b_3 are regression coefficients and an intercept, and Y_m is a working memory capacity. The multiple correlation obtained by this equation should be highest when performance is optimal because there occurs no overlapping between *ri* and *ii* in working memory, and lower when performance is worse because the above equation does not hold owing either to the over-lapping or to the remaining surplus spaces in working memory.

As for the second statement, namely, disordinal interaction between anxiety and task difficulty, suggestive of the interaction of two inverted U-shapes, we find many example in previous researches.

Tennyson and Woolley (1971) obtained a clear disordinal interaction between state-anxiety and task difficulty, and the task was to classify poems into positive and negative instances of meter types (Fig. 4). We reversed the direction of ordinate to be in line with that of Fig. 2.

Okamoto (1977) obtained similar disordinal interaction between anxiety level and two types of programmed material (Fig. 5). The random sequence is usually more difficult than logical sequence, and this interaction pattern also roughly fits to the theoretical crossover in Fig. 2. However, the curves are U-shaped, and not inverted U-shaped with the reversed direction of ordinate.

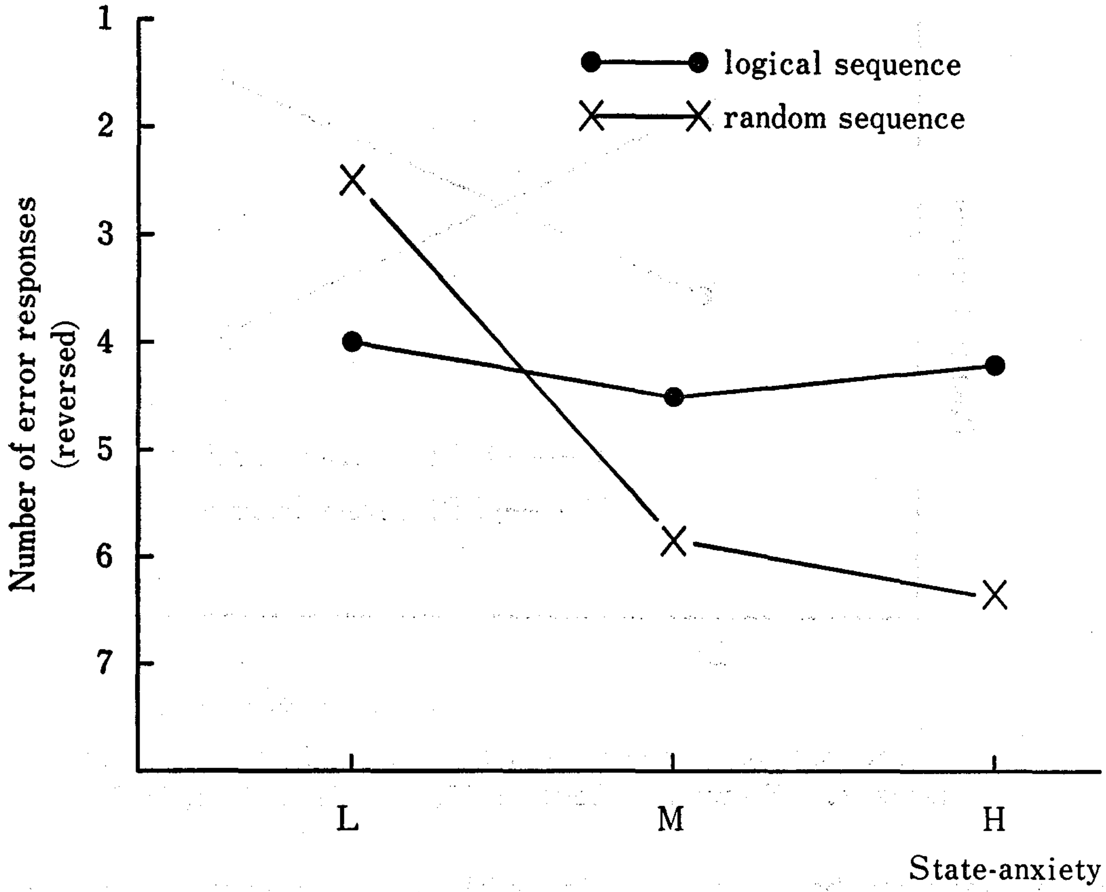

Fig. 5 The relation between level of state-anxiety and the structure of instructional program. (Redrawn from Okamoto, 1977)

Trown and Leith (1975) found exactly the same disordinal interaction as in Fig. 4 between anxiety level and two teaching strategy (Fig. 6). Because discovery learning capitalizes aptitude of learners, and structured learning compensates it, the former is usually more difficult than the latter.

Schmeck (1983) found a disordinal interaction between level of neuroticism and two types of similarity among response words in paired associate learning (Fig. 7). The figure is based on data of students of low Deep-Processing, namely, students who have not developped deep-processing style of learning defined by Inventory of Learning Process. If high phonetic similarity is more difficult than high semantic similarity for this type of students, the interac-

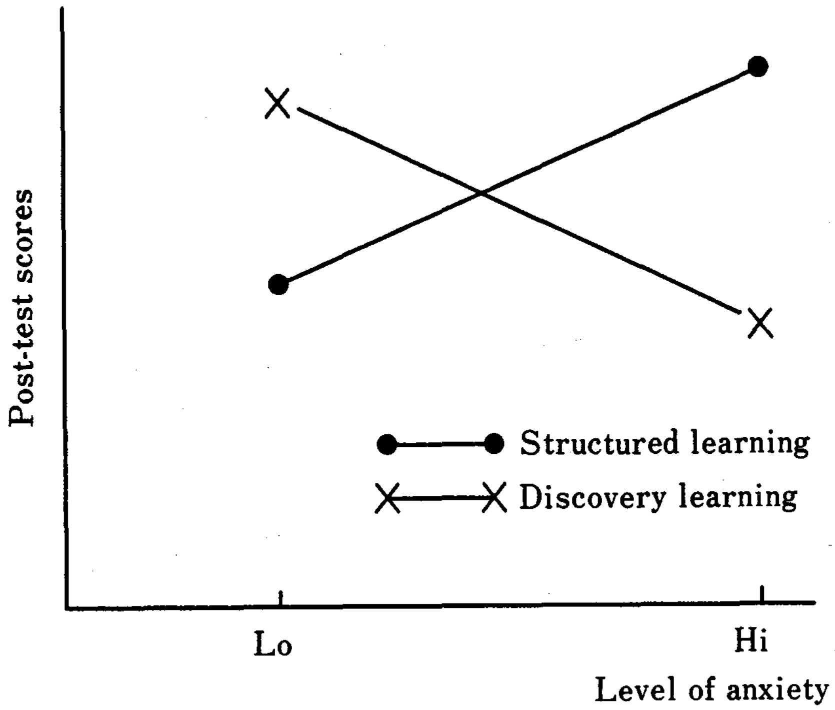

Fig. 6 The relation between anxiety level and two teaching strategies. (Trown and Leith, 1975; Entwistle, 1981, 1987)

tion pattern can be said to coincide with that of above figures, but it is difficult to tell which type of similarity is more difficult to process.

As regards the U-shaped regression, we reanalysed all of available data from our own experiments conducted in educational settings, or outside of laboratory (Namiki, 1977; Namiki, et al., 1978; Kage, et al., 1989; Kage and Namiki, 1990; Fukunaga, et al., 1991) by plotting payoff onto anxiety dimension as abscissa, or by using multiple regression analysis including squared or quadratic term as an independent variable. We were not successful in finding U-shaped regression as far as our data were concerned. Similar pattern of disordinal interaction as shown in above figures was not obtained either, although a significant disordinal interaction appeared with opposite direction (Namiki, et al., 1978; Namiki, 1990).

We calculated multiple correlation using posttest score as a

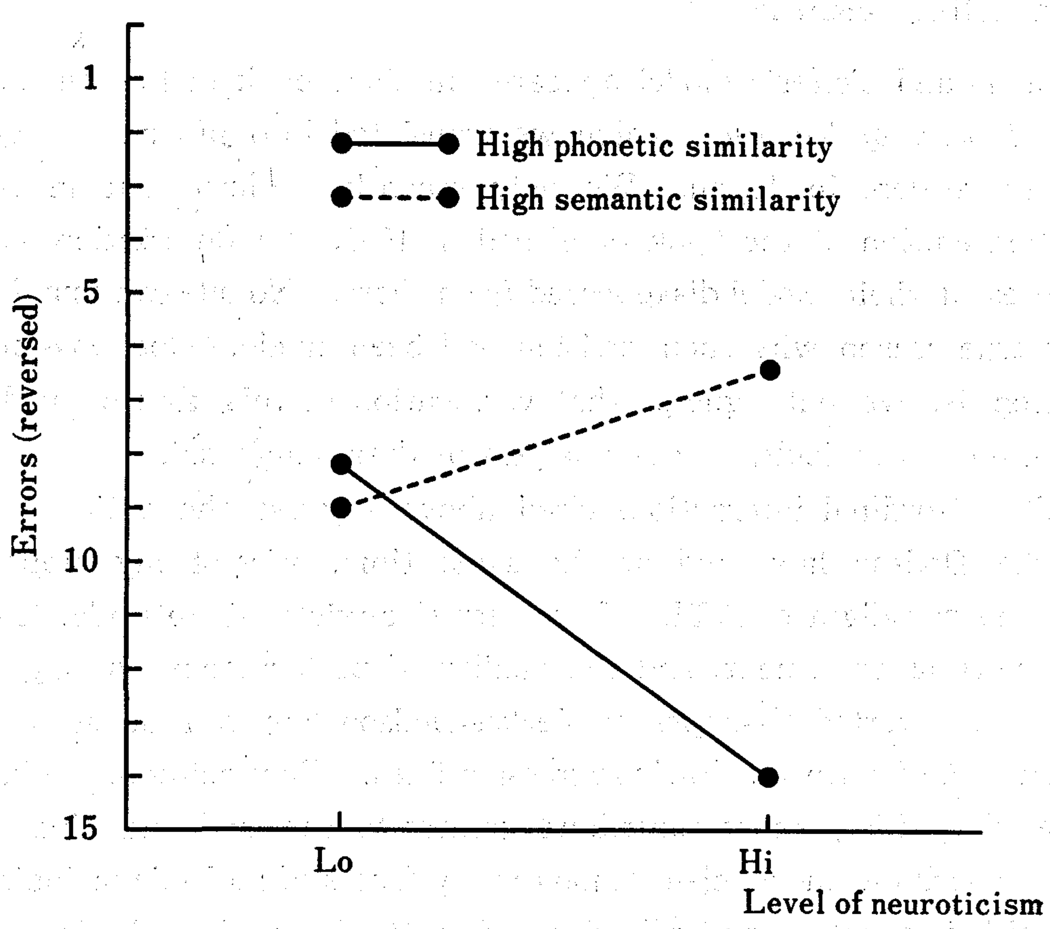

Fig. 7 The relation between level of arousal and the type of similarity among response words. (Adapted from Schmeck, 1983)

measure of *ri*, anxiety as that of *ii*, and digit span as that of working memory capacity. We obtain, for example, $R=.483$ at the highest in one set of data (Kage, et al., 1989), and the value was significant. This is a partial evidence favorable to Biggs' theory. The *Rs* in three instructional conditions, Program solving group, Traditional and curriculum-based group and Programmed-instruction group were .483, .461, and .384, respectively, and thus the latter half of the condition 3 was not supported although the relative difficulty levels of these three instructional treatments were not examined.

Concluding remarks

Biggs and Telfer's model appeared in their book in 1981 entitled *The process of learning*, which we translated into Japanese to get wider readers in Japan. We only recently noticed that in the second edition of the book published in 1987, the description and figures of their model disappeared from there. No one can imagine the true reason why such revision had been made. One possibile reason is, we only guess, that verification of this kind of model is often too difficult, as our analysis of data suggested.

The disordinal interactions cited above suggest the validity of Yerkes-Dodson law, and at the same time, offer strong support for the paradigm of ATI. If we regard anxiety as aptitude, task difficulty as treatment, and the quality of performance as payoff, the two inverted U-shapes of Yerkes-Dodson law can be seen as typical ATI with quadratic regression lines. Theorizing of the law offered by Biggs must contribute greatly to the understanding of the underlying mechanism among many facets of aptitude including cognition, conation and affection. And the bulk of works in substanciating such a theory remains to be done.

References

Baddeley, A., 1986, *Working memory*. Oxford University Press.

Biggs, J. B. and Telfer, R., 1981, *The process of learning*. Prentice-Hall of Australia, Japanese edition translated by Namiki, H., Iwata, S., Fujitani, T. and Nagai, S., *Psychology for teachers and parents*: *The process of education and learning*. Keimeisha, 1985.

Biggs, J. B. and Telfer, R., 1987, *The process of learning*. 2nd edition, Prentice-Hall of Australia.

Case, R., 1985, *Intellectual development*: *Birth to adulthood*. Academic Press.

Easterbrook, J. A., 1959, The effect of emotion in cue utilization and the organization of behavior. *Psychol. Review*, **66**, 3, 183–201.

Entwistle, N., 1981, *Styles of learning and teaching*: *An integrated outline of educational psychology*. John Wiley.

Entwistle, N., 1987, Explaining individual differences in school learning.

In E. DeCorte, H. Lodewijks, R. Parmentier and P. Span (Eds.), *Learning and instruction: European research in an international context. vol. 1.* Pergamon Press/Leuven Univ. Press.

Flavell, J. H., 1978, Comments on Case's paper. In R. S. Siegler (Ed.), *Children's thinking: What develops?,* L.E.A.

Fujitani (Kawata), T. and Namiki, H., 1982, Information-processing approach in the Aptitude-Treatment Interaction (ATI) research. *Philosophy,* Keio Univ., **75**, 207–235.

Fukunaga, N., Kurahachi, J., Nakano, T., Kage, M., Suto, T. and Ando, J., 1991, The effectivness of the Communicative Approach on EFL (English as a foreign language) beginners: The comparative research on the two EFL teaching methods. *Studies in Sociology, Psychology and Education,* Keio Univ., **31**, 117–126.

Hamilton, V., 1979, Information processing aspects of neurotic anxiety and schizophrenics, In V. Hamilton and D. M. Warburton (Eds.), *Human stress and cognition: An information processing approach.* John Wiley.

Hockey, R., 1979, Stress and the cognitive components of skilled performance. In V. Hamilton and D. M. Warburton (Eds.), *Human stress and cognition: An information processing approach.* John Wiley.

Jensen, A. R., 1987, The *g* beyond factor analysis. In R. R. Ronning, et al. (Eds.) *The influence of cognitive psychology on testing. Buros-Nebraska Symposium on measurement and testing. vol. 3.* Hillsdale.

Kage, M., Mogami, Y. and Namiki, H., 1989, Effect of structurization in teaching of arithmetics. Proceedings of 31st Annual Conference of Japanese Association of Educational Psychology, p. 349.

Kage, M. and Namiki, H., 1990, The effect of evaluation structure on children's intrinsic motivation and learning. *Japanese J. educ. Psychol.,* **38**, 36–45.

Kawata (Fujitani), T., Naito, T., Namiki, H., Yamamoto, J., and Yasuoka, R., 1979, Experimental verification of Mental-Space theory and its problem at issue. *Studies in Sociology, Psychology, and Education,* Keio Univ., **19**, 91–97.

Mandler, G., 1979, Thought processes, consciousness, and stress. In V. Hamilton and D. M. Warburton (Eds.), *Human stress and cognition: An information processing approach.* John Wiley.

Namiki, H., 1977, Teaching-learning process seen as a statistical interaction. Unpublished doctorial dissertation, Keio Univ.

Namiki, H., 1982, Operation and working memory capacity. In K. Hatano and S. Amaiwa (Eds.), *Development of Piagetian psychology, vol. 2.* Kokudosha.

Namiki, H., 1990, Pessimism in educational psychology: In the case of ATI research. *Philosophy,* Keio Univ., **90**, 101–118.

Namiki, H. and Hayashi, J., 1977, Determination of optimal instructional treatment in ATI of two aptitude dimensions and multiple treatments. *Japanese Psychol. Research*, **19**, 2, 56–67.

Namiki, H., Hayashi, J., Shibata, T., 1978, Specificity-Generality of aptitude information in the Aptitude-Treatment Interaction: An experimental evidence. *Philosophy*, Keio Univ. **68**, 145–162.

Näätänen, R., 1970, The inverted-U relationship between activation and performance: A critical review. In S. Kornblum (Eds.), *Attention and performance. IV*. Academic Press.

Okamoto, T., 1977, The study of differences on learning behavior by the patterns of State anxiety—Trait anxiety in relation to programmed learning. *Japanese J. educ. Psychol.*, **25**, 2, 13–24.

Schmeck, R. R., 1983, Learning style of college students. In R. F. Dillon and R. R. Schmeck (Eds.), *Individual differences in cognition. vol. 1*. Academic Press.

Snow, R. E., 1989, Aptitude-Treatment Interaction as a framework for research on individual differences in learning. In P. L. Ackerman, R. J. Sternberg and R. Glaser (Eds.), *Learning and individual differences: Advances in theory and research.* W. H. Freeman.

Tennyson, R. D. and Woolley, F. R., 1971. Interaction of anxiety with performance on two levels of task difficulty. Proceedings of the Annual Convention of the American Psychological Association, 6, (Pt. 1), 377–378.

Trown, E. A. and Leith, G. O. M., 1975, Decision rules for teaching strategies in primary schools: Personality-treatment interactions. *British J. educ. Psychol.*, **45**, 130–140.

Yerkes, R. M. and Dodson, J. D., 1908, The relation of strength of stimulus to rapidity of habit-formation. *J. comparative Neurology and Psychol.*, **18**, 459–482.