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Yerkes–Dodson: A Law for All Seasons

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Abstract. The paper traces the vicissitudes of the Yerkes–Dodson law from 1908 to the present. In its original form, the law was intended to describe the relation between *stimulus strength* and *habit-formation* for tasks varying in *discrimination difficultness*. But later generations of investigations and textbook authors have rendered it variously as the effects of punishment, reward, motivation, drive, arousal, anxiety, tension or stress upon learning, performance, problem-solving, coping or memory; while the task variable has been commonly referred to as difficulty, complexity or novelty, when it is not omitted altogether. These changes are seldom explicitly discussed, and are often misattributed to Yerkes and Dodson themselves. The various reformulations are seen as reflecting conceptual changes and current developments in the areas of learning, motivation and emotion, and it is argued that the plasticity of the law also reflects the vagueness of basic psychological concepts in these areas.

There are not many 'laws' in psychology. Nor are there many references to research going back to the beginning of the century. In both respects, the so-called 'Yerkes–Dodson law' from 1908 forms an exception which deserves attention—perhaps especially from those who value stability and permanence in science. The idea of a 'law' implies that we are dealing with 'a basic relationship in nature' (Levitt, 1967) which seems to have stood the test of time through more than 80 years of changing psychological fashions.

Against this background, it is disturbing to discover that successive generations of psychologists cannot agree as to what this celebrated law actually states. Winton (1987) found reference to Yerkes and Dodson's work in 9 out of 25 introductory textbooks, but in all cases the findings were presented 'anachronistically'. This is a mild statement. Instead of reflecting 'a basic relationship in nature', versions of this particular 'law' seem to mirror the currently most popular concepts in the psychology of learning, emotion and motivation. Bartlett's (1932) serial reproduction subjects could not have been capable of rendering *The War of the Ghosts* with more levellings, sharpenings and normalizings than modern psychologists are of retrieving Yerkes–Dodson's law from their collective long-

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term store. They agree in only one, graphically prominent respect: that the law somehow involves a curvilinear relationship. They differ in most others: Is there just one, or are there several curves? What are the variables? Are they of a theoretical or behavioural nature?

The present paper provides an overview of the variety of interpretations given to the Yerkes–Dodson law from 1908 to the present. I am not primarily concerned with the validity of the law, its importance or the psychological principles involved, but focus on some of the historical, psychological and theoretical reasons for its transformations. The law can also be studied as an illustrative case of the problems involved in formulating and applying a psychological principle. Its vicissitudes can be regarded as a demonstration of the mutability and fuzziness of allegedly 'basic' psychological concepts, especially in the area of motivation and emotion.

The Original Formulation

In their original paper, Yerkes and Dodson (1908) reported three 'sets' of experiments on discrimination learning with dancing mice. The mice were to acquire what the authors describe as a 'white–black discrimination habit', by receiving a non-injurious electric shock whenever they entered a white box (or passageway), as compared to no shock in a parallel black passageway.

In their first set of experiments, Yerkes and Dodson started giving very weak shocks, but found that it took the mice too long to learn the habit to perfection (10 out of 10 correct discriminations for three consecutive days). When they stepped up the stimulus strength, fewer trials were needed, but at the third and strongest level of shock the number of trials (or 'tests') needed to reach the criterion went up again. According to the authors themselves, this was an unexpected finding, contrary to their hypothesis that the rate of habit-formation would continue to increase with increasing strength of the electric stimulus. Instead, an intermediate degree of stimulation proved to be most favourable.

Yerkes and Dodson felt that these 'preliminary results' needed 'a more exact and thoroughgoing examination of the relation of strength of stimulus to rapidity of learning' (1908, p. 472), which they decided to do by making the discrimination task easier (by allowing more light to enter the white box), and using five rather than three levels of shock.

As predicted, the learning speed went up, but the U-curve was not reproduced. Although the weakest stimulus still gave the slowest rate of learning, the strongest stimulus now led to the most rapid learning (see Figure 1). This made the authors puzzled for the second time. 'The results of the second set of experiments contradict those of the first set. What does this mean?' (1908, p. 474). Could it have something to do with the easiness of the discrimination task?

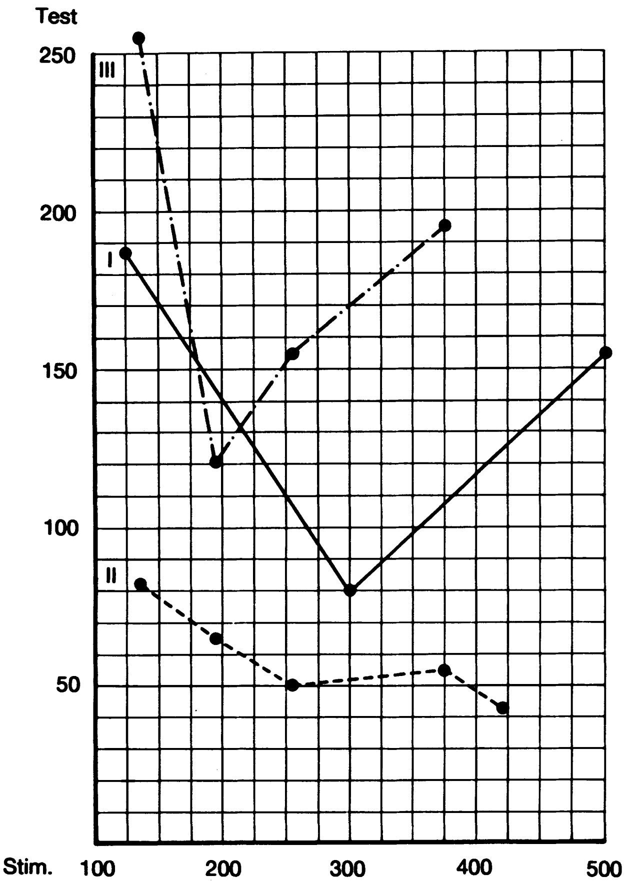


FIGURE 1. Yerkes and Dodson's original curves, relating the number of trials ('tests') to reach the learning criterion to strength of stimulus. (Adapted from Yerkes & Dodson, 1908, p. 479.)

To test this possibility a third set of experiments was conducted in which the discrimination task was supposed to be even more difficult than in Set I (by allowing less light into the passageways). There were four levels of shock, but only two mice in each condition, as against four mice per condition in the previous sets. As can be seen from Figure 1, the mice needed a number of trials for perfect learning to occur. The most efficient learning seemed to occur at the second weakest shock level.

On this basis, Yerkes and Dodson concluded that both weak and strong stimuli can result in slow habit-formation. The most favourable stimulus strength depends upon the nature of the task. '*As the difficultness of discrimination is increased the strength of that stimulus which is most favorable to habit-formation approaches the threshold*' (1908, p. 481).

This, then, is the original formulation of what has later been known as the Yerkes–Dodson law. From a contemporary point of view, the law and its background show several interesting features.

(a) The 'law' seems to have been accidentally discovered; it was certainly not theoretically derived. On the contrary, Yerkes and Dodson expected a monotonic relationship, but found a curve; when trying to replicate the U-curve with an easier task they found something more like a linear function.

(b) Although empirically derived, the empirical basis of the law in these first sets of experiments is—by modern standards—rather unsystematic and sketchy.

The curves are based on averages from 2–4 subjects per condition, no statistical tests are performed (we had still to wait 30–40 years for Fisher and the 'inference revolution' in experimental psychology: Gigerenzer & Murray, 1987). On the other hand, in the spirit of the early experiments (Danziger, 1985), the article includes tables showing the performance of each and every mouse for each and every day of the experiments. These tables also show a lot of inter-mouse variability, but in the absence of any statistical analysis we have to trust the authors when they say that 'we are convinced that these differences do not invalidate the conclusions' (Yerkes & Dodson, 1908, p. 478). We have also to accept the authors' conviction that the apparent linear function of Set II represents the first, descending part of a U which would have been fully uncovered had they subjected their animals to even stronger levels of stimulation. Their statement: 'We present this conclusion tentatively, subject to correction in the light of future research' (p. 481), sounds like an empty formula, as the authors go on to announce: 'Of its correctness we feel confident because of the results which the other sets of experiments gave' (p. 481).

Furthermore, the study loses some of its elegance when we realize that the three curves are based on different stimulus strength values (3, 4 and 5 levels; the strongest shocks used are different for each of the three tasks). Such a design is, of course, unthinkable for a present-day ANOVA-educated experimenter, which may be the reason why even Winton (1987), in his attempt to recover the Yerkes–Dodson law from its anachronistic interpreters, describes the original study as a 3 × 3 design with three levels of task difficulty and three levels of stimulus strength. (Of course, such a design could not reveal three differently peaked Us.)

These flaws in the experimental design (lack of a factorial design, and the smallness of the samples) have led a later critic, W.P. Brown (1965), to suggest that the 'law' should be buried in silence.

(c) There is no discussion of the concepts involved. To the animal experimenter of 1908, speed of habit-formation is speed of habit-formation and nothing else. The tasks vary in 'difficultness of discrimination', and strength of shock is simply 'strength of stimulus' with no attempt to speculate about its aversiveness, or its emotional or motivational significance. The spirit of scientific objectivity is emphasized by the terminology; for instance, when the authors refer to a weak shock as 'a stimulus approaching the threshold'.

So instead of calling for new research to clarify how these relationships should be explained—whether they apply to other learning tasks, or even to tasks outside the field of learning; whether they generalize to positive as well as to negative stimuli; whether they are mediated by processes of attention, memory or motivation—Yerkes and Dodson seemed perfectly satisfied to record a behavioural function between the experimentally induced variables. Apparently their only concern was if these relationships could be generalized to other species.

Early Replications and Interpretations

Following Yerkes and Dodson's suggestion, replications of the original study were performed by Cole (1911), using chicks, and Dodson (1915), with kittens. Cole gave his chicks an easy, medium and difficult discrimination task, with four levels of shock for the medium task and three for the other two tasks. Rapidity of learning increased with strength of shock in the easy task. In the medium task the strongest shock seemed to slow down the learning process, whereas, for the difficult task, strong shock increased the variability of performance: three chicks apparently profited by the shock, whereas two failed to accomplish the discrimination altogether (the sixth chick in this condition showed a promising record, until suffering an untimely death on the tenth day of the experiment). Cole concluded that his results were generally in agreement with Yerkes–Dodson, even if he only observed one, nearly flat U-curve (in the medium difficultness condition).

Dodson (1915) trained four kittens to discriminate between a light and a somewhat darker box by giving them a 'medium' shock whenever they entered the darker box. These did better than another group of four kittens that were given a 'strong' electric shock. When the discrimination task was made less difficult, a strong and a medium shock proved about equally effective. Finally, with an even easier task, learning improved with shock strength. There were only two kittens in the 'less difficult' and 'easy' discrimination conditions, and no U-curves, yet the results were clearly compatible with the original Yerkes–Dodson formulations. Dodson concluded that for easy tasks rate of 'habit formation increases as the unpleasantness is made greater'.

The latter formulation implies a first move away from the objectivistic description, 'strength of stimulus', towards a more psychological concept. But following Thorndike (1913, 1932), the central concepts of learning theory between 1915 and 1935 were neither 'strength of stimulus' nor 'unpleasantness' but *rewards* and *punishments*.

In a pioneering study, Dodson (1917) himself found that strength of rewards as well as strength of punishments were curvilinearly related to rapidity of learning. For instance, discrimination learning in white rats was facilitated when they were rewarded by food after they had been starved for up to 41 hours prior to the experiment. If they were starved longer (and food was presumably still more rewarding), learning became less efficient. Interestingly, in this article Dodson did not refer to his own 1908 and 1915 publications. Possibly he did not find them relevant since the new experiment contained no manipulation of the difficulty of the discrimination variable. This gives us a hint that the originators of the 'law' may have regarded the difficulty factor a more essential part of it than the U-shaped function.

Later writers did not doubt that the Yerkes–Dodson law was actually about the relationship of punishment to learning. Thus Young (1936), after discussing the research of Yerkes and Dodson (1908), Cole (1911) and Dodson (1915) in detail, adds a study by Vaughn and Diserens (1930) with human subjects showing maze learning to be more efficient with light and medium punishment than with either heavy punishment (strong electric shocks) or no punishment at all. In this study there was only one degree of difficulty. Young concludes: 'For the learning of every activity, there is an optimum degree of punishment' (1936, p. 287).

Drive and Performance

During the 1930s and 1940s, three developments in the psychology of learning occurred which were to change and broaden the Yerkes–Dodson law into a far more pervasive principle than its originators could ever have imagined. First, the idea of *punishment* as a fundamental learning principle was discarded (Thorndike, 1932; Skinner, 1938; Estes, 1944). Second, a distinction was introduced between the concepts of learning and performance (Tolman, 1935, 1938; Hull, 1943). If punishment was to have an effect, it had to be motivational (on performance), rather than reinforcing (on learning). Third, the concept of *drive* (originally formulated by Woodworth, 1918) came into prominence as the central principle of motivation, the general energizer of behaviour, necessary for bridging the gap between competence (learning) and performance (behaviour).

Accordingly, the Yerkes–Dodson law was sometimes reinterpreted as a law about the relationship between motivation and learning, and sometimes as a law about the relationship between motivation and performance. Young, who in his 1936 book on motivation described it as a law of optimal strength of punishment, rendered it in his next book (on emotion) as a principle of optimal motivation (Young, 1943). Irwin referred to it somewhat more precisely as 'an interesting result of *negative* motivation' (1951, p. 230). But usually the negative element went unnoticed, presumably because the current concept of drive did not distinguish in any theoretically important way between negative and positive motives. According to the Hull–Spence formula, all activity is motivated by drive-reduction, which is basically of a negative nature. Thus Hilgard and Marquis (1961, p. 230) took the law as evidence that 'under certain conditions, drive may actually interfere' with learning, Broadhust (1957) described it as a law about 'the optimum motivation for a learning task', and J.S. Brown spoke about an 'optimal motivation for learning' (1961, p. 91).

All these formulations were made by authors who seemed to know the original studies, at least in outline, and can be defended if we accept that the original 'strong stimuli', alias 'punishments', have their primary effect as a source of motivation. This is, however, an assumption that never seems to have been explicitly discussed. According to Broadhurst (1959), the difference between the original law and the 'optimum motivation' formulation is just a matter of psychological 'jargon'.

Later authors have been more eager to attribute the motivation/drive formulation to Yerkes and Dodson, quoting them as having 'looked at the efficiency of maze learning in mice, varying two things: the difficulty of the task, and the strength of the drive' (Mook, 1987, p. 211). In the same vein, a contemporary psychological dictionary defines the law as 'strong motivation interferes with learning a difficult discrimination-problem but helps to learn a simple one' (Zusne, 1987, p. 308).

A significant further step is taken by those who prefer to speak about 'performance' rather than 'learning'. Easterbrook comments upon 'the up and down relationship between proficiency and drive that is familiar in connection with the names of Yerkes and Dodson' (1959, p. 193). 'According to this "law", increasing the intensity or level of motivation will result in poorer performance' (McCullers, 1978, p. 6). Variants of this more general formulation have persisted in textbooks as well as in scientific articles designed to test aspects of the law. Here is an example from the glossary of an introductory textbook: 'Increased motivation will improve performance up to a point, beyond which there is deterioration. The easier a task is to perform, the higher the drive level for optimal performance' (Bourne & Ekstrand, 1973, p. 480). In an experimental test of the Yerkes–Dodson law Hochhauser and Fowler claim that 'the law . . . posits that high drive will interfere with performance in difficult discriminations' (1975, p. 262); whereas Saavedra, Abarca, Arancibia and Salinas discuss their research results 'within the theoretical framework of the Yerkes–Dodson Law, which states a relationship between drive level, performance, and different degrees of task difficulty' (1990, p. 107).

In these and similar formulations, the law is freed from its humble origin within the psychology of learning, and has become a more general principle of motivated behaviour. It also changes its geometrical orientation from U-curves to inverted Us: Whereas learning is naturally measured in terms of number of trials, number of errors, etc., making the optimum the *low* point on a learning curve, performance is more easily scored as the more the better, identifying the optimum with the *high* point on an inverted U. Hence the Yerkes–Dodson law in contemporary psychology is almost exclusively drawn in terms of inverted U-curves (cf. Figures 3 and 4).

The Revived Yerkes–Dodson Law and the Arousal Concept

Scattered references to the Yerkes–Dodson law in the 40-year period between 1915 and 1955 do not mean that the law was regarded as a principle of central importance. It is seldom mentioned in introductory textbooks and often absent even from comprehensive texts on learning. Nor is it to be found as an entry in standard dictionaries of psychology, like Warren (1934), Harrison (1947), Drever (1952) and English (1958). One reason may be that the dominant learning theories of this period were not very historically oriented, and tended to make as little reference as possible to their pre-behaviouristic forebears. Another reason may have been the vague empirical and theoretical status of the law itself.

A look at contemporary psychology gives us a different picture. References to Yerkes–Dodson can be found in at least one out of three introductory textbooks (Winton, 1987) and in every respectable dictionary of psychology (e.g. Chaplin, 1985; Petrovsky & Yaroshevsky, 1987; Statt, 1990; Stratton & Hayles, 1988; Sutherland, 1989; Zusne, 1987). To what do we owe this flood of renewed interest?

We have already touched upon one factor. By expanding its scope from a special principle of discrimination learning to a general relation between motivation and performance, the law was given a potential its originators never could have dreamed of. What it needed was a stronger empirical and theoretical basis. Between 1955 and 1960 it got both.

In a series of experiments, Broadhurst (1957) did what Yerkes and Dodson had failed to do, namely provide a complete factorial design (4 motivation levels × 3 difficulty levels) with a sufficient number of subjects (10 rats in each condition). The task was again one of brightness discrimination, but the motivation, air deprivation, was varied by holding the rats under water for 0, 2, 4 or 8 seconds. The highest score for easy discrimination was found in the 4 seconds group. For medium and difficult tasks the optimum moved down to 2 seconds. Broadhurst also proposed to extend the law to individual differences in drive level by comparing the

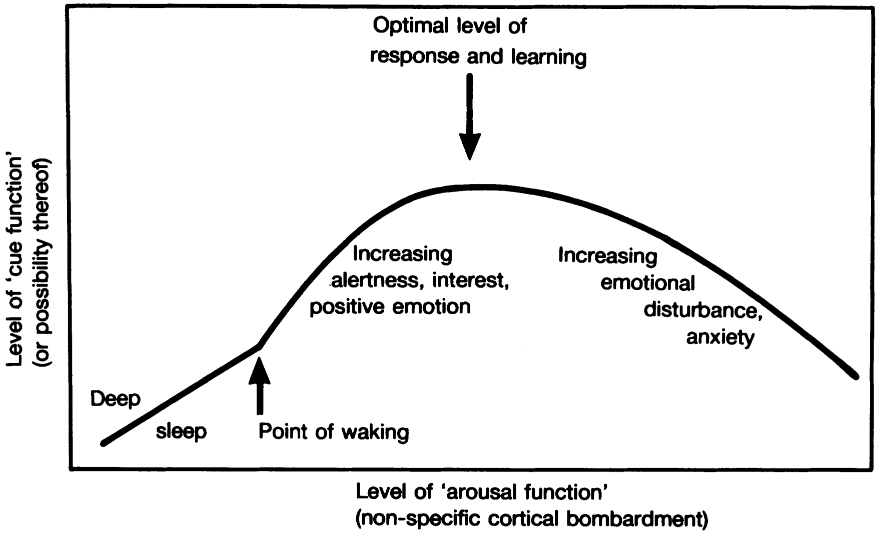


FIGURE 2. The relationship between 'arousal function' and 'cue function', according to Hebb. (Adapted from Hebb, 1955, p. 250.)

performance of rats differing in 'emotionality' (as measured by the open field test). In a later article, Broadhurst (1959) announced 'a revival' of the Yerkes–Dodson law, as a principle of far-ranging applicability, especially in the field of abnormal psychology. The law seemed ready to leave the animal laboratory even if it still had its best supporters among rats and mice.

The revival would have been less successful were it not for the simultaneous introduction of the concept of *arousal*. In his seminal paper on the arousal concept, Hebb (1955) introduced the inverted U (see Figure 2) to describe the relationship between arousal and performance (variously described as 'adjustment', 'effective behavior' and 'cue function'). The arousal concept was designed to supplant the traditional behaviouristic drive concept, moving the psychology of motivation/emotion from the organism's periphery to its centre, from the viscera to the nervous system, from the body to the brain. It had the advantage of being thought of alternatively as a behavioural, physiological or purely theoretical concept, and made good sense to summarize existing research findings in the areas of learning, motivation and emotion.

Interestingly, Hebb does not mention the Yerkes–Dodson tradition in his 1955 paper. Nor did Schlosberg (1954) and Duffy (1957) in their original discussions of the curvilinear relationship between activation/arousal, and efficiency or quality of performance. But for others, the similarity between Hebb's and Yerkes–Dodson's inverted Us was too great

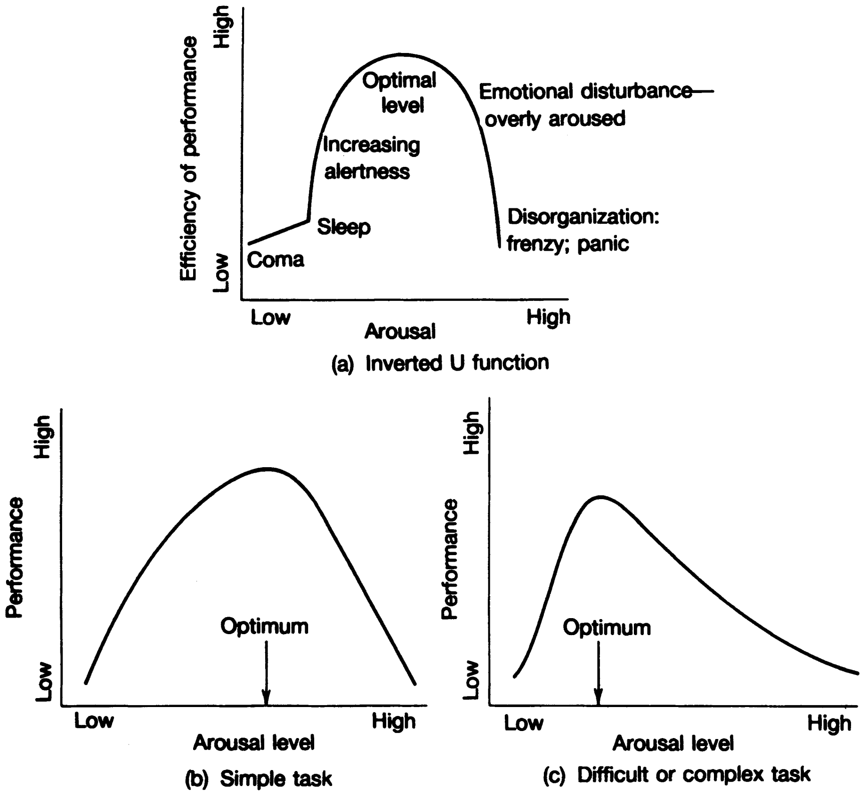


FIGURE 3. Illustrative example of the Hebb/Yerkes–Dodson hybrid. *Source:* From *Motivation: Biosocial approaches* (p. 126) by S.B. Klein, 1982, New York: McGraw-Hill. Copyright © 1982 by McGraw-Hill. Reprinted by permission.

to resist. From about 1960, the most frequent description of the Yerkes–Dodson law is in terms of the relationship between arousal and performance. Even after researchers started doubting the fruitfulness of a unitary concept of arousal (Lacey, 1967), textbook authors have persisted in describing the Yerkes–Dodson law in arousal terms (Winton, 1987). A good graphical example is provided by Klein (1982). Here, the Hebb function (identifiable by the figure legend, as well as by the sharp bend of the curve at the transition point between sleep and wakefulness) is described in the figure caption as '(a) Inverted U-shaped relationship between arousal and performance predicted in the Yerkes–Dodson law' (p. 126). The Hebb curve is accompanied by two smoother functions which purport to show that 'the optimum level is higher in a simple task than in (c) a complex task' (see Figure 3).

The Hebb/Yerkes–Dodson hybrid has not been limited to textbook presentations, but has become a standard also in research literature investigating the relationship between arousal and performance (e.g. Anderson & Revelle, 1983; Geen, 1948; Matthews, 1985). It has also received its theoretical interpretations, the major theory going back to Easterbrook (1959), who suggested that arousal (and emotional level) tends to narrow the range of cue utilization. Moderate levels of arousal will improve performance by helping the individual to concentrate on relevant cues (leaving out the irrelevant ones), whereas higher levels may be detrimental because relevant cues may also be excluded. Even though Easterbrook does not refer to Hebb, and mentions the Yerkes–Dodson law only in passing, this theory has become the standard explanation of the Hebb/Yerkes–Dodson hybrid.

Anxiety, Stress and Efficient Coping

The concept of arousal has been credited for bridging the gap between the psychology of motivation and the psychology of emotion. It has also been blamed for blurring the distinction between these two fields. The ground was already prepared through its predecessor, the drive concept, which sometimes has been identified with emotionality, and even anxiety; especially after Taylor (1951) constructed the Manifest Anxiety Scale as an attempt to operationalize and measure the Hullian concept of generalized drive. So we should not be surprised to find reformulations of the Yerkes–Dodson law in which the concepts of fear, anxiety, emotionality, tension, drive and arousal are used interchangeably.

For instance, Levitt, in his book on 'the psychology of anxiety', contends that 'the Yerkes–Dodson Law holds that the relationship between fear, conceptualized as drive, and learning is *curvilinear*' (1967, p. 117). He goes on to report findings on human maze learning by Stennett (1957) and Matarazzo, Ullet and Saslow (1955) as support of this view. Stennett varied his subjects' degree of motivation, whereas Matarazzo et al. had subjects varying in anxiety proneness (as measured by the Taylor Manifest Anxiety Scale). Both found U-shaped performance functions, but the original publications contain no references to Yerkes–Dodson.

Similarly, Broadhurst (1959) calls upon the law to explain why neurotic subjects (who presumably suffer from more generalized anxiety, as measured by the Manifest Anxiety Scale) are easier to condition than non-neurotics, whereas they learn more slowly when exposed to other, more difficult tasks.

In a recent essay entitled 'Anxiety and Cognition', M.W. Eysenck interprets the Yerkes–Dodson law as saying that 'high levels of arousal, motivation, or anxiety lead to improved performance up to a certain level, after which further increases impair performance' (1989, p. 323).

This hypothetical relationship is reiterated in the current literature on *stress*. The following quotation is fairly typical: 'A little anxiety from time to time can be beneficial to task performance. . . . This is illustrated by the Yerkes–Dodson law which states that performance is improved by anxiety until an optimum level of arousal is reached' (Dobson, 1982, p. 14).

The peaceful coexistence of motivational and emotional terms in these definitions makes it easy for the reader to believe that choice of concept does not make much of a difference. Still, it is possible to detect a subtle shift in informational content. As long as the Yerkes–Dodson law is interpreted as a principle of motivation, the most interesting part of the curve is the descending, or right-hand, slope. To say that performance increases with motivation is a triviality, to say that it also can be detrimental is not. The descending portion of the curve has also been the most difficult to observe empirically (W.P. Brown, 1965; Hochhauser & Fowler, 1975). On the other hand, everyone knows that anxiety (and other emotions) beyond a certain level can be non-adaptive and impair performance. So what attracts interest in this area is primarily the left-hand, ascending part of the curve, implying that up to a point increased anxiety or emotionality may be for the good (cf. the above quotation). We would not be very impressed to hear: 'A little *motivation* from time to time . . . can be beneficial for task performance'! So perhaps the concepts of motivation and emotion are still too different to be covered, without further discussion, by the same law.

The many-sidedness of the arousal concept has made it possible to link the Yerkes–Dodson law to phenomena so far apart as personality traits and effects of physiological stimulants. The law has (with variable success) been applied to account for theoretical differences in intellectual performance by extroverts and introverts under time pressure (Revelle, Amaral, & Turriff, 1976), under different noise conditions (Geen, 1984; Matthews, 1985), and at different times of day (Matthews, 1985), as well as by subjects, differing in impulsiveness, working under the influence of caffeine (Anderson & Revelle, 1983; Anderson, Revelle & Lynch, 1989).

From Discrimination Difficulty to Task Complexity

Hebb's arousal/performance curve was not the only inverted U to become popular in the 1960s. Studies of stimulus preference, curiosity and intrinsic motivation had revealed similar relationships between stimulus variables like intensity, complexity, discrepancy, novelty, incongruity and informativeness, on the one hand, and preference or interest, on the other (Berlyne, 1960; Haber, 1958; Hunt, 1963). This relationship was often assumed to be mediated by degree of arousal. So we may not only perform better under conditions of intermediate arousal, but also prefer stimuli and tasks that have a medium arousing potential. On this background, it is not surprising to discover references to the Yerkes–Dodson law among the proponents of this new trend in the psychology of motivation (e.g. Fiske & Maddi, 1961; White, 1959).

In this context, the Yerkes–Dodson task variable of 'difficultness of discrimination' did not make much sense. It had already been commonly rendered as 'task difficultness' in general (cf. above). Now it seemed to be time to specify the difficultness concept again, and what could be more appropriate than *task complexity*? Again, Yerkes and Dodson are given full credit for the anachronism. 'They showed that maximum motivation did not lead to the most rapid solving of problems, especially if the problems were complex' (White, 1959, p. 321). Now, it is hard to imagine one black/white discrimination as being more complex than another, although it can certainly be more difficult. At the same time, the mice are credited with solving problems, which, together with the idea of complexity, gives the Yerkes–Dodson law a human twist particularly suited to support the new trend in motivation theory.

Yerkes and Dodson could now be used as historical forerunners for those who wanted to criticize the Hullian one-dimensional concept of drive reduction as the sole motivator of behaviour. Bolles (1967) described the law as an alternative to the simple view of drive as energizer. Fiske and Maddi (1961) posited that an intermediate level of drive, tension or stimulation would be more attractive than either too much or too little. Similarly, Lepper and Greene (1978) challenged the concept of reward by claiming that it can 'turn play into work' by interfering with intrinsic motivation. Rewards also can be too much or too little. Again, Yerkes–Dodson came in handy to counterbalance the more recent authorities of Hull and Spence. According to McCullers, 'it seems clear that the Yerkes–Dodson law could predict a detrimental effect of reward in some situations' (1978, p. 7). Both McCullers and McGraw (1978), writing on the same subject, contrast the Yerkes–Dodson law with the Hull–Spence theory, using the former to shed doubt upon the latter.

Two-dimensional Representations

The idea of an interaction of two variables on a third one demands a three-dimensional imagination and a lot of information-processing capacity, especially if one of the relationships is curvilinear and the nature of the variables a matter of taste. So why not simplify the law and forget about the task variable altogether? After all, the inverted U is the best part of it, and if you have seen one, you have probably seen them all.

Accordingly, a number of contemporary formulations of the law leave out the difficulty factor altogether. We can find them in textbooks, dictionaries (e.g. Chaplin, 1985; Sutherland, 1989), and even in research papers testing predictions from the law. Thus Deshpande and Kawane (1982) predicted moderately anxious subjects to be superior to both high- and low-anxious groups on a memory task, whereas Mills (1985) discussed the relationship between physiological arousal and efficiency of coping in patients with anorexia nervosa. In none of these cases is any mention made of different optima for different tasks (see Figure 4[A]).

In keeping with the plasticity of the law, the nature of the dependent variable (the label of the abscissa) will vary according to the psychological concept of current interest. For the psychiatrist it will be 'efficiency of coping' (Figure 4[A]), for the cognitive psychologist it will be cognitive efficiency, in one form or the other. In all cases, Yerkes and Dodson and their versatile mice seem to have anticipated it. 'It has long been assumed that arousal and cognitive efficiency are strongly interrelated. Yerkes and Dodson (1908) attempted to generalize this relationship by proposing an inverted U-formed relation between tension or arousal and performance' (Christianson & Nilsson, 1989, p. 297). Here, Yerkes and Dodson are credited with generalizing a principle these modern investigators have in mind.

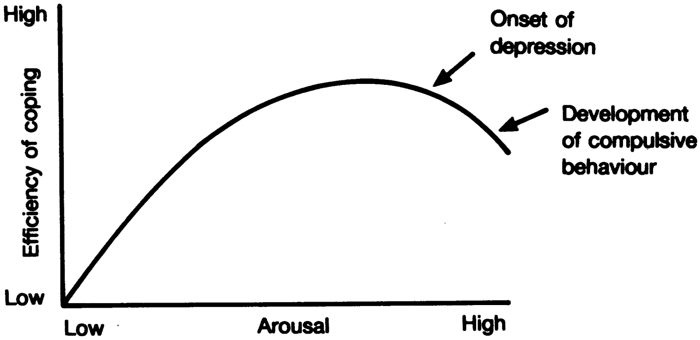
Recently, the Yerkes–Dodson law has even been taken to court, helping the memory expert to illuminate jurors on the tricky question of eyewitness testimony. Relating her experiences as an expert witness, Elizabeth Loftus writes: 'I approached the backboard located in front of the jury box and with a piece of chalk drew the upside-down U shape that represented the relationship between stress and memory known to psychologists as the Yerkes–Dodson Law' (Loftus & Ketcham, 1991, pp. 194–195). The curve referred to is reproduced in Figure 4(B). Needless to say, it bears more of a similarity to Hebb's single curve (Figure 2) than the set of curves discussed by Yerkes and Dodson. And since the eyewitness expert is concerned about memory, the curve has to relate arousal (or 'stress') to efficiency of memory (rather than to learning, performance, problem-solving, efficiency of coping, or any of the other concepts available).

Conclusions

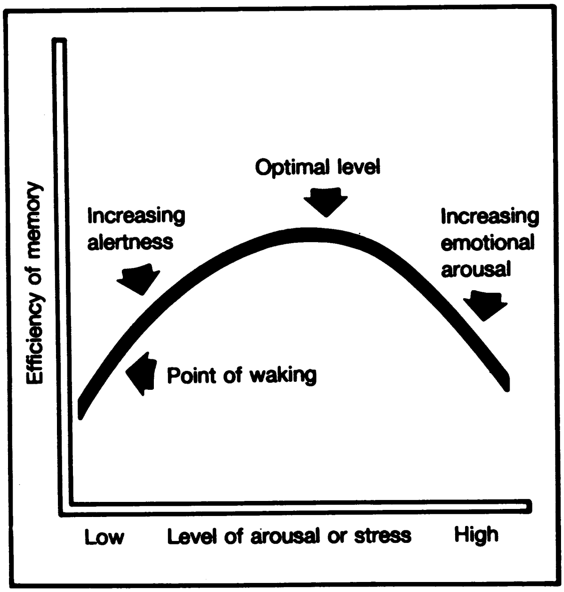
What is the scientific status of the Yerkes–Dodson law?

So far, we have not tried to evaluate the law's validity, generality and empirical support because these issues are so heavily dependent upon how the law itself is formulated. For instance, it is relatively easy to demonstrate that high levels of tension and stress can interfere with intellectual performance, whereas the potential dangers of excessive positive motivation are harder to prove.

Theoretical explanations will also differ, depending upon what is to be explained. Typically, drive/learning formulations have been given explana-



A The relationship between arousal and efficiency (Yerkes–Dodson curve), indicating the points at which depression and compulsive behaviour tend to appear.



B The Yerkes–Dodson law.

FIGURE 4. Simplified 'Yerkes–Dodson' curves, intended to illustrate the occurrence of psychiatric symptoms (A), and the quality of eyewitness memory under extreme stress (B).

Source: A: Adapted from 'The neuronal basis of compulsive behaviour in anorexia nervosa and related disorders' by I.H. Mills, 1985, *Journal of Psychiatric Research*, *19*, p. 233. Copyright © 1985 by Pergamon Press Ltd. Reprinted by permission. B: Adapted from *Witness for the defense* (p. 195) by E. Loftus and K. Ketcham, 1991, New York: St Martin's Press. Copyright © 1991 by Elizabeth Loftus and Katherine Ketcham. Reprinted by permission.

tions in terms of S–R theory, whereas arousal/task performance formulations are explained by cognitive variables.

Thus Eysenck (cited in Broadhurst, 1959) speculated that *drives* may energize incorrect as well as potentially correct habits in a problem situation. An increase of motivation will accordingly serve to delay the emergence of a correct habit in a difficult as opposed to a simple situation (with less incorrect behaviours possible). Other explanations have been given by evoking the Hullian concept of drive stimuli which presumably could elicit interfering responses (Jones, 1959). Brown and Herrnstein (1975) assume that the Yerkes–Dodson law works because of interfering *drive-specific responses*, which typically emerge at high drive levels.

A related mechanism was discussed by Zajonc (1965) in his theory of social facilitation. Zajonc proposed that the presence of others will be detrimental for unfamiliar tasks, but faciliate the performance of well-rehearsed activities, on the assumption that arousal tends to strengthen dominant response tendencies, but inhibits the formation of new ones. Zajonc did not refer to Yerkes–Dodson, but again the similarity has been noted by others and seen as compatible with the Yerkes–Dodson curves (Bourne & Ekstrand, 1973).

The effects of *arousal* on performance and problem-solving have most commonly been explained in terms of Easterbrook's (1959) concept of relevant and irrelevant cues, mentioned earlier. With increased arousal fewer cues are processed, thereby excluding irrelevant ones. But later even cues relevant for the task in question may be lost. An alternative explanation has been launched by Humphreys and Revelle (1984), based on the assumption that arousal increases attention and persistence, but reduces efficiency of information processing (e.g. retrieving information from memory). Both these theories predict that optimal arousal will vary from task to task. For instance, high levels of arousal will be more detrimental for tasks requiring a wide range of peripheral cues (Easterbrook), or for tasks heavily relying upon retrieval from memory (Humphreys and Revelle).

The different interpretations and explanations of the Yerkes–Dodson law reviewed here may be symptomatic of something more general than just divergent views about the law itself. In fact, very few discussions of the law even mention the existence of divergent views. Typically, the current view is posthumously attributed to Yerkes and Dodson themselves, or if not, it is implied that the differences in formulation are immaterial and that we are all basically speaking about the same curves. In view of the variety of concepts used (cf. Table 1) this position requires a lot of theoretical flexibility and/or conceptual vagueness. How can strength of stimulus, motivation, anxiety and stress be considered interchangeable concepts? Yet several authors are willing to perform this conceptual glissando, spanning the gap from Yerkes to Easterbrook and beyond, even in the same breath. In

TABLE 1. Overview of concepts used by various authors to describe the Yerkes–Dodson law

Independent variables		Dependent variable
Stimulus strength	Discrimination difficulty	Habit-formation
Degree of punishment	Task difficulty	Learning
Intensity of motivation	Task complexity	Proficiency
Drive level	Task novelty	Performance efficiency
Magnitude of reward		Quality of performance
Level of arousal		Efficiency of coping
Emotionality		Problem-solving
Anxiety		Efficiency of memory
Tension		
Stress		
. .	. .	. .

Note: Almost any concept in the first column can be combined with almost any concept in the third column, with or without interaction with task variables (second column).

the biographical entry for 'Yerkes, Robert Mearns (1876–1956)' in a modern encyclopedia of psychology, we can find the following characteristic passage:

> From his experiment he formed a theory called the Yerkes–Dodson law. It states that there is an optimal level of *arousal* for *tasks*, and that moderate levels of *motivation* facilitate *problem solving and change*. If *stress* is too high, the individual may not process *relevant cues* for *learning*; if it is too low, irrelevant and relevant cues will be processed indiscriminately. (Haynie, 1984, p. 481; my emphasis)

Misrepresented historical contributions are not uncommon in psychology (cf. Farr, 1983; Friend, Rafferty, & Bramel, 1990; Harris, 1979; McCullough, 1983; Samelson, 1980; Vicente & Brewer, 1993). Typically, recent ideas are projected onto the past, providing present theories with a real or imagined historical anchor. To do so, one or both of the following conditions have to be met:

(a) Historical ignorance. Only secondary or tertiary sources are used, the original contributions referred to are no longer consulted. As a result, misrepresentations will go uncorrected and establish themselves as a kind of scientific folklore. Exceptions occur: in the extensive textbook literature of the last 30 years, I have been able to find three cases in which Yerkes and Dodson's work has been rendered approximately correct (Hall, 1961; Brown & Herrnstein, 1975; Roediger, Rushton, Capaldi, & Paris, 1987).

(b) Conceptual vagueness. The fact that the Yerkes–Dodson law can take so many different shapes tells more about the scientific standards and status of the area of investigation than about the law itself. Obviously, we are still far from having satisfactorily mapped out the fields of motivation, emotion and task performance, even at a conceptual level. It is safe to say

that the Yerkes–Dodson law will never be conclusively established or disproved as long as long as it can be taken to predict any dynamic variable to have almost any (facilitating or inhibting) effect upon any desired task.

A more benevolent interpretation would be to assume that the Yerkes–Dodson curves reflect a basic relationship to be observed between a *variety* of psychological variables. Even if one acknowledges a number of distinctions between concepts listed in each column of Table 1, it is conceivable that most of them are related to each other in a similar way and behave according to the same general pattern. If this were the case, it would be possible to admit the difference between Yerkes and Dodson's original findings and later reformulations and still refer to the same 'law'.

Accordingly, some authors seem to take the variety of interpretations as evidence of the robustness and generality of the law rather than as a sign of historical and conceptual confusion. A quotation from a recent textbook in cognitive psychology illustrates the point:

> There is a relationship among short-term memory, arousal, and task complexity, called the Yerkes–Dodson law. Yerkes and Dodson (1908) originally found that the relationship applies to *learning*. Hebb (1955) and others pointed out that it also applies to *performance* of things already learned. (Martindale, 1991, p. 129)

Martindale goes on to assert that the law 'applies to everything from . . . people making decisions . . . to rats making brightness discrimination under water' (p. 130).

But there have also been sceptical voices observing that the law's widespread popularity seems out of proportion to its actual empirical support (Bäumler, in press: W.P. Brown, 1965). Recently, Günther Bäumler (1992) has re-examined the original data from Yerkes and Dodson's 1908 paper and has reached the surprising conclusion that the Yerkes–Dodson law perhaps never existed.

Bäumler observes two problems with the original design that seem to have gone unnoticed by previous critics. One has to do with the levels of the difficultness variable, and the other with the learning criterion.

1. In the original study, difficultness of discrimination was manipulated by adjustable openings, allowing more or less light to enter into the passageways. There were no photometer readings, but the authors report the areas of the openings. From these figures it is evident that the 'easy' condition is characterized by a large brightness difference between the two passageways. The 'medium' and 'difficult' tasks differ in the total amount of light allowed to enter the boxes, but the contrast between the black and white passageways remained the same in both cases. Thus there is no *a priori* reason to assume that Set III differed from Set I in difficultness of discrimination.

2. The original performance measure was number of trials to reach the criterion of three errorless series of 10 trials each (one series per day).

TABLE 2. Mean learning scores from the original Yerkes–Dodson experiment according to Bäumler's (1992) reanalysis (numbers of animals in parentheses)

Discrimination difficultness	Stimulus strength		
	Weak	Medium	Strong
Series criterion of Yerkes and Dodson			
Easy task (Set II)	11.25 (4)	8.75 (8)	7.88 (8)
Difficult task (Set I & III)	22.00 (6)	13.88 (8)	19.83 (6)
Errors criterion of Bäumler			
Easy task (Set II)	10.50 (4)	9.25 (8)	10.13 (8)
Difficult task (Set I & III)	20.50 (6)	20.67 (8)	13.67 (6)

Source: The data are from Tables 5 and 6 in 'Eine kritische Revision des "Yerkes–Dodson Gesetzes" von 1908' by G. Bäumler, 1992, in H. Gundlach (Ed.), *Psychologische Forschung und methode—Das Versprechen des Experiments. Festschrift für Werner Traxel* (pp. 46–47), Passau: Passavia Universitätsverlag. Adapted by permission.

This, according to Bäumler, is a poor measure of learning, as it does not reflect improvements in performance but rather what happens *after* most of the learning has taken place. Instead, Bäumler suggests a measure based on the number of errors from days 2 to 6 (before the first mouse reached Yerkes–Dodson's series criterion and was removed from the experiment).

Baumler further suggests, for computational purposes, a grouping of stimulus strengths (electric shocks) into three levels: weak (125 and 135 units), medium (195, 255 and 300 units) and strong (375, 420 and 500 units). With two levels of difficulty (Set II vs Sets I and III), this gives a 2 × 3 design with 4–8 animals in each cell. Mean scores according to Yerkes–Dodson's series criterion and Baumler's error criterion are presented in Table 2.

The table shows performance on the easy task to be almost unaffected by strength of stimulus, at least according to the errors criterion. The difficult task gives rise to an inverted U function by the series criterion, but not with the errors criterion, by which performance improves with increasing strength of stimulus. Even if these reanalyses yield significant interactions between the difficultness and the strength of stimulus factor, they do not lend much support to the basic Yerkes–Dodson idea that difficult tasks require less stimulation for optimal performance than do easy tasks. Alternative groupings of stimulus strength, and substituting medians for mean scores, show essentially the same picture.

These reanalyses underscore the discrepancy between the schematic, idealized textbook presentations of the 'law', and its more messy empirical and historical basis. The 'ubiquitous' inverted Us, overlapping domes (e.g. Sdorow, 1990, p. 341), pyramids (e.g. Martindale, 1991, p. 130), waves, bells and mountains claimed to illustrate the Yerkes–Dodson law may be of considerable didactic, heuristic and even theoretical value; but when it comes to the question of their origin, it is tempting to answer with Brehmer's (1980) Lockean paraphrase: 'In one word: not from experience.'

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