CLASSICAL CONDITIONING: A CONCEPTUAL REVOLUTION

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INTRODUCTION

In his seminal work *The Structure of Scientific Revolutions* first published in 1962, with a second edition in 1970, Thomas Kuhn offered an intriguing account of how progress occurs in a science. Traditional textbook accounts of progress in a given scientific discipline such as physics, chemistry, or biology often seem to imply, if only by default, that progress is attributable simply to a gradual, linear accumulation of information over time, the end result being the current state of knowledge in that field. Opening chapters in introductory science textbooks often list in chronological order the significant discoveries in the field over its lifespan and perhaps provide some basic biographical detail about the individuals who made such discoveries. The implication would seem to be that current knowledge and understanding derives directly from these past accomplishments.

Dissatisfied with such simplistic accounts of the driving force of progress in science, Kuhn's great contribution was to introduce the concept of a paradigm which, in his estimation, sets the perspective and determines the goals and methodologies which scientists in a given area of study will adopt in their pursuit of knowledge. The paradigm offers, in a sense, a particular view of reality. It represents a pattern of thinking which orders the world and activities of the scientist in a way which seems, of all possibilities, to be the most consistent with the reality of nature, itself.

A paradigm may take the form of a theory or model which provides, within its jurisdiction, a general description of nature to which most practitioners in that field subscribe during periods of what Kuhn calls "normal science". By definition, a paradigm cannot be absolutely precise for the information which would allow such precision (and, perhaps, transform the paradigm into a law) is not yet available. For Kuhn, the job of the typical scientist in a period of "normal science" amounts to a kind of "puzzle solving" activity, the purpose of which is to refine the match between the paradigm and that aspect of nature which it describes. From Kuhn's perspective, identifying novelties of theory or fact is not the goal of "normal science" and such novelties are not expected if the paradigm has been providing an adequate description of that aspect of nature to which it is relevant.

At various times during a period of "normal science", anomalous data are bound to appear which, by definition, are not consistent with the view of nature encapsulated in the reigning paradigm. In many instances, minor adjustments in the existing paradigm are sufficient to handle these anomalous data. Perhaps it is a problem of methodology which, when resolved, eliminates the anomaly. In other cases, the challenge to the paradigm may be severe enough to provoke a crisis of confidence about its validity. If that crisis cannot be resolved within the framework of the existing paradigm, then the stage is set for what Kuhn calls a "scientific revolution".

Although scientific revolutions are relatively rare, they represent the focal or turning points on which progress in a scientific enterprise depends. Like a political revolution, a scientific revolution involves a complete change in, or overthrow of, the existing order (paradigm). A new paradigm emerges which is qualitatively different from its predecessor. It is the product of a transcendent cognitive process and not simply a minor re-arrangement of old and new facts. All existing data (including the anomalous data which could not be handled by the earlier paradigm) are interpreted in a new light. In Kuhn's estimation, this is akin to a Gestalt-like shift in perception. A new reality emerges which is qualitatively different from the reality embodied in the deposed paradigm. The scientist sees his world in a new light and enters upon a new period of "normal science" guided in thought and action by the basic tenets of the new paradigm.

In Kuhn's estimation, no mature science exists in the absence of paradigms. An overriding paradigm in physics is relatively theory. Darwin's theory of evolution by natural selection seems to fulfill a similar role in biology. As a relatively young science, psychology does not yet possess an overriding paradigm and, indeed, may never do so, given the extreme complexity of its subject matter. However, paradigms may exist at various levels of analysis and psychology is now sufficiently mature as a science to claim to possess paradigms at least at the level of specific phenomena.

In a mature science, knowledge or facts are not compiled in a vacuum but under the auspices of paradigms which set the perspective and guide the activity of the scientist. Scientists operating under the auspices of a paradigm tend to be conservative by nature, so scientific revolutions are relatively few and far between. Novelty tends to be suppressed unless, or until, it poses such a threat to the established paradigm that it simply can no longer be ignored.

Conservatism is not normally associated with progress but, ironically, it is the very existence of paradigms which, in Kuhn's estimation, guarantees progress in science despite the apparent constraints they impose on scientists. A reigning paradigm establishes the context against which all existing and future data can be evaluated. Indeed, anomalous data could only be identified as such against the backdrop of an existing paradigm. As the arbiter of its own demise, the paradigm thus becomes the servant of progress in science. Dramatic progress in science may thus owe much more to error than is generally recognized.

Over the last half century or so, an intriguing variation on Kuhn's theme seems to have been played out in the evolution of thinking about the nature of the "simple" associative learning phenomenon known as classical, or Pavlovian, conditioning. The way in which progress has been achieved in understanding this phenomenon seems to be well described by Kuhn's concept of a paradigm shift which results in a qualitative change in the way a particular phenomenon is viewed by scientists. The revolution in thinking about classical conditioning, at least with respect to organisms of intermediate phylogenetic level, relates to two major themes: (1) the behavioural domain of classical conditioning or, to put it another way, the significance of classical conditioning as a process of behavioural adaptation to the environment; and (2) the very nature of the conditioning process, itself. The burden of this paper is to explore in some detail the evolution of thinking on these issues in light of Kuhn's (1962) account of how progress (new understanding) is achieved in science. The vehicle to this end is an examination of the historical narrative relating to classical conditioning, beginning with a brief consideration of the role of behaviour, particularly species-typical or "instinctive" behaviour, as a means of adapting to environmental demands.

Behavioural Adaptation to the Environment

The ability to adapt to environmental demands is the essential challenge posed to individuals of all species, regardless of their phylogenetic level. The anatomical and physiological characteristics which the individual brings to its environment via phylogeny form the basis for behavioural adaptations (species-specific reaction patterns) which, in many species, are relatively, or even completely, impervious to modification through individual experience in the environment. These species-specific, biologically adaptive responses are the legacy the individual acquires via heredity as a consequence of that long process of "trial and success" which marked the evolution of the species of which it is a member (Lorenz, 1965).

Species-specific reaction patterns, which seem to owe their origin and adaptiveness primarily to phylogeny, have often been described as "instinctive" in contrast to other so-called "learned" or "acquired" forms of behaviour. Charles Darwin (1872, cited by Barnett, 1962) spoke of instinctive actions as being stereotyped behavioural sequences which develop in the animal without the benefit of practice, imitation or any other process which could conceivably be defined as learing. Spalding (1873) distinguished between two basic forms of behaviour in the organism's repertoire—learned behaviour patterns and inborn behaviour patterns, the "instincts". Even J.B. Watson (1925), the founder of behaviourism, differentiated between acquired and inherited behaviour patterns, although he suggested that there is often no need for the psychologist to stress such a distinction except in those instances where resolution of the problem under investigation in the laboratory is better served by overemphasizing, if necessary, the extent of this distinction.

Staddon (1983) has pointed out that for many species, inborn reaction patterns are not enough, in and of themselves, to ensure successful adaptation to the environment. This seems to be especially true of species in which the lifespan of the individual is extended and/or the environment is subject to short-term changes which may be of adaptive significance but for which phylogeny has been unable to prepare the individual. In such instances, individuals of a given species may well be endowed by phylogeny with a capability for behavioural modification through learning. In the simplest instance, the learning which occurs seems to be related exclusively to the sensory (eliciting) component of the species-specific reaction pattern.

A species-specific reaction pattern is characterized by two basic components — (1) the sensory component, which involves an internal representation of particular stimulus configurations in the environment, and, (2) the response component, which may consist of both autonomic and motor (skeletal) elements, and which is triggered automatically or reflexively by an encounter with the critical stimulus configuration(s). Ethologists such as Lorenz (1965) refer to the sensory component as the "innate releasing mechanism" (IRM) which is programmed in such a way that the response pattern with which it is associated is normally evoked only in biologically appropriate circumstances. Modifying the selectivity of the IRM is, in Lorenz's estimation, a critical role for learning. Classical, or Pavlovian, conditioning would seem to be a major way by which such modifications in selectivity are achieved.

Classical (Pavlovian) Conditioning–The Early Contributions of I.P. Pavlov

Classical, or Pavlovian, conditioning is often considered to be the simplest form of associative learning, although recent evidence suggests that the process is considerably more complex than early theorists had imagined. To I.P. Pavlov (1849-1936), the Russian physiologist, goes the credit for being the first to carry out systematic explorations of this associative learning phenomenon (Pavlov, 1927,1930, 1934). In the course of his investigations, Pavlov developed what might be considered to be the first paradigm describing this type of learning. Whether Pavlov's account of classical conditioning can be said to have had the status of a full-fledged paradigm is, perhaps, debatable, but it is clear that he made the first definitive statements regarding such critical issues as the behavioural domain of classical conditioning, the nature of the conditioning process, itself, and the methodology appropriate to its investigation. Naturally, it was against Pavlov's original assertions that reaction occurred, particularly on the part of certain psychologists in the United States, and this may be considered the beginning of an evolutionary process which eventually led to a new view of classical conditioning as an associative learning phenomenon.

Classical conditioning is based, in the first instance, on the existence of inborn, unlearned or unconditioned reaction patterns acquired by the individual via phylogeny. These species-specific reaction patterns are triggered without benefit of learning by particular stimulus configurations in the environment. In Pavlovian terminology, the stimulus configuration, which Lorenz (1935) labeled the IRM, is known as the unconditioned stimulus (US), while the reaction which it unconditionally evokes is known as the unconditioned response (UR).

Working on the physiology of digestion (for which he received the Nobel Prize in 1904), Pavlov would place food (the US) in the stomach of a hungry dog in order to observe the gastric secretions (UR) evoked by the food stimulus. In the course of his investigations, he observed at some point that stimuli associated with the delivery of food to the stomach eventually acquired the ability to evoke gastric secretions themselves, although initially, they had been neutral in this regard. The discovery of these new, acquired, learned, conditioned or, as Pavlov called them, "psychic reflexes", marked a major turning point in his career. Convinced that he had discovered a phenomenon and a procedure which would open the door to an objective and scientific investigation of the physiology of "mind", Pavlov spent the rest of his distinguished career exploring the various subtleties of the conditioning process.

Moving from the gastric reflexes of the stomach to the salivary reflex in the mouth (which presented far fewer surgical complications), Pavlov and his colleagues embarked on a long series of experiments which focused, for the most part, on the reflexive response of salivation to food or acid placed in the mouth of a dog. Pavlov's basic procedure was to pair an initially neutral stimulus such as a tone, a light, or the sound of a metronome with food or acid in the mouth which unconditionally elicited a salivary response. The eventual result of a series of such pairings was that the light or tone would acquire the capacity to elicit a salivary response. In Pavlovian terminology, the initially neutral stimulus is called the conditioned stimulus (CS) and the eventual reaction to the light is known as the conditioned response (CR).

Classical conditioning thus leads to a situation in which inborn reaction patterns come to be expressed in the presence of stimuli which have a history of consistently and reliably signaling the imminent appearance of a biologically significant event (the US). In terms of the contingency operating in classical conditioning, the only requirement for the appearance of the US (also called the reinforcer) is the prior occurrence of the CS signaling its imminent occurrence. Ongoing behaviour of the subject is irrelevant in this regard.

The Behavioural Domain of Classical Conditioning – Pavlov's Perspective

Although Pavlov (1927) used the autonomic response of salivation almost exclusively in his investigations, this was largely in the interests of experimental precision and objectivity. From Pavlov's perspective, the use of this response carried no particular implications about the range of behaviour encompassed by the concept of the UR (and, by implication, the CR). Writing with particular reference to the URs elicited by food and acid, he contended that:

> It is essential to realize that each of these two reflexes – the alimentary reflex and the mild defence reflex to rejectable substances – consist of two distinct components, a motor and secretory. Firstly, the animal exhibits a reflex activity directed towards getting hold of the food and eating it, or, in the case of rejectable substances, towards getting rid of them out of the mouth; and secondly, in both cases, an immediate secretion of saliva occurs, in the case of food, to start the physical and chemical processes of digestion and, in the case of rejectable substances, to wash them out of the mouth. We confined our experiments almost entirely to the secretory component of the reflex: the allied motor reactions were taken into account only where there were special reasons. The secretory reflex presents many important advantages for our purpose. It allows

> of an extremely accurate measurement of the intensity of reflex activity.... It would be much more difficult to obtain the same accuracy of measurement for any motor reflex, especially for such complex motor reactions as accompany reflexes to food or rejectable substances.
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> – Pavlov (1927, pp. 17-18)

Elaborating on the UR elicited by food, Pavlov noted that:

> This activity of the salivary gland cannot be regarded as anything else than a component of the alimentary reflex. Besides the secretory, the motor component of the good reflex is also very apparent in experiments of this kind. In this very experiment, the dog turns in the direction from which it has been customary to present the food and begins to lick its lips vigourously.
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> – Pavlov (1927, p. 22)

It is clear from the preceding passages that Pavlov regarded autonomic and motor responses as equally valid components of the total unconditioned reaction to a US. Two factors seem to have been important in his decision to concentrate on the former (salivation). In the first place, the salivary response allowed more precise, quantitative measurement than did the complex motor reaction. Additionally, he wished to minimize the possibility of anthropomorphism which he saw as a threat to objective analysis of the motor component, and he believed that motor responses were more likely to tempt him toward such subjectivism. But, as Pavlov was well aware, to concentrate on the autonomic component was usually not a simple matter of neglecting the motor component. He often found it necessary to actively suppress the motor component by installing experimental animals in a restraining harness.

Pavlov went a step further in terms of the type of behaviour which he felt the concept of the UR (and, by implication, the CR) could legitimately encompass. Addressing the question of whether reflexive behaviour and "instinctive" behaviour (e.g., courtship, aggression, nest-building, etc.) are qualitatively different, he concluded that no clear line of demarcation could be detected between them. One could conceive of instinctive behaviour as a complex reflexive pattern, a chaining of individual reflexes:

> It follows from all this that instincts and reflexes are alike, the inevitable responses of the organism to internal and external stimuli, and therefore we have no need to call them by different names. Reflex has the better claim of the two in that it has been used from the very beginning with a strictly scientific connotation.
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> – Pavlov (1927, p. 11)

With the notion of a second signaling system which took into account human language capabilities, Pavlov extended the generality and relevance of his formulation to the human situation. For Pavlov, it seemed that the way had been cleared for objective, physiologically oriented investigations of even the most complex functions of the cerebral hemispheres.

The Nature of the Conditioning Process – Pavlov's Perspective

Regarding the nature of the conditioning process, Pavlov's observations suggested that stimuli bearing an appropriate temporal relationship to the US can come to function as conditioned stimuli (CSs) capable of eliciting conditioned responses (CRs) which are frequently indistinguishable in form from the UR. Pavlov accounted for this outcome with a principle of "stimulus substitution" which is well illustrated in his reference to an experiment in which the beating of a metronome served as the CS for a food US:

> The sound of the metronome is the signal for food and the animal reacts to the signal in the same way as if it were food; no distinction can be observed between the effects produced on the animal by the sounds of the beating metronome and showing it real food.
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> – Pavlov (1927, p. 22)

Pavlov elaborated on the nature of this stimulus substitution process in several of his later writings, introducing the directional aspects of the conditioned response as a critical refinement:

> Let us take any natural phenomenon that has never had any relation either to food motion or to food secretion. If this phenomenon precedes the act of eating, once or several times, it will later provoke a food reaction; it will become, so to speak, a surrogate for food – the animal moves toward it and may even take it into its mouth, if the object is tangible.
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> – Pavlov (1930, p. 209)

> The first reaction elicited by the established conditioned stimulus usually consists in a movement toward the stimulus, i.e., the animal turns to the place where the stimulus is to be found. If the stimulus is within reach, the animal even tries to come in touch with it, namely, by means of its mouth. Thus, if the conditioned stimulus is the switching on of a lamp, the dog licks the lamp; if the conditioned stimulus is a sound, the dog will even snap in the air (in the case of very heightened food excitability). In this way, the conditioned stimulus actually stands for the animal in place of food.
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> – Pavlov (1934, p. 187)

Thus, it seems clear that Pavlov regarded classical conditioning as a process in which the CS acquires the properties of a substitute for or surrogate of the US which it signals. It follows that the CS should not only elicit a CR similar or identical in form to the UR but should also be the object at which the CR is directed if the CR has a directional component and the CS is a tangible object which can be localized in space.

Behavioural Domain of Classical Conditioning – Reaction Against Pavlov's Assertions

Pavlov considered the conditioned reflex to be the primary and universal element on which much more complex forms of behaviour could be generated. As news of his discoveries spread to America, there were some who saw in his methodology a powerful tool to be used in the study of associative learning. Foremost among these was J.B. Watson, the founder of the American school of behaviorism who, in 1925, in a volume entitled *Behaviorism*, not only embraced the conditioned reflex as a powerful research tool but even went so far as to credit the Pavlovian process with all but the most elementary components (the elementary reflexes) of an organism's behavioural repertoire.

However, the explorations of the American psychologist E. L. Thorndike (1898, 1911) with the instrumental learning method, in which a contingency is arranged between a response and a reinforcer, clearly raised the possibility of two distinct forms of conditioning, each with its unique behavioural domain. Miller and Konorski (1928) accepted a distinction between Type I and Type II conditioning, the former corresponding to classical conditioning with its stimulus-reinforcer (CS-US) contingency and the latter to instrumental learning with its response-reinforcer contingency.

In his seminal work *The Behaviour of Organisms*, B.F. Skinner acknowledged a similar distinction, coining the terms Type S and Type R to refer to classical and instrumental (or operant) conditioning, respectively. In Skinner's estimation, Type S (also known as respondent) conditioning was limited to responses mediated by the autonomic nervous system plus a few scattered skeletal responses such as the eyeblink and the knee-jerk. In

Skinner's words,

> The formula for Type S conditioning is applicable, if at all, only within a limited field. Much of the plausibility given to the extension of Type S has come from a confusion with Type R, which arises from the fact that most of the stimuli which elicit skeletal respondents are also reinforcing stimuli for Type R. It is difficult to set up conditions for Type S which are not also the conditions for Type R.
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> – Skinner (1938, p. 112)

A dichotomy was thus drawn between respondent and operant behaviour which resolved essentially along the involuntary/voluntary, autonomic/skeletal dimensions. The overwhelming proportion of motor behaviour which Pavlov had considered amenable to classical conditioning was recast by Skinner in terms of the discriminated operant of the Type R variety. In Skinner's words,

> The distinction between Type R and S arising from their confinement to operant and respondent behaviour respectively implies a rough topographical separation. Reflexes of Type S, as respondents, are confined to such behaviour as is originally elicited by specific stimuli. The effectors controlled by the autonomic nervous system are the best examples, one of which was used almost exclusively by Pavlov in his classical studies. This subdivision of behaviour is a very small part of the whole field as described here, and much if it is perhaps excluded if the definition is interpreted strictly. To it may perhaps be added a few scattered skeletal responses – flexion of a limb to noxious simulation, winking, the knee-jerk, and so on. Most of the experiments of skeletal behaviour which have been offered as paralleling Pavlov's work are capable of interpretaton as discriminated operants of Type R. . . . It is quite possible on the evidence that

> a strict topographical separation of types following the skeletal-autonomic distinction may be made.
>
> – Skinner (1938, p. 112)

Skinner's views were very influential and the net effect in America at least was to reduce classical conditioning in the eyes of many investigators to a relatively minor process of behavioural modification, even in organisms of intermediate phylogenetic level. Given that Skinner's views commanded wide allegiance among investigators, it might be suggested that this new view of the behavioural domain of classical conditioning represented a qualitative change in emphasis akin to what Kuhn (1970) has defined as a paradigmatic shift.

The Nature of the Conditioning Process – Reactions Against Pavlov's Perspective

Regarding the nature of the conditioning process, we have seen that, in the first instance, Pavlov emphasized the importance of temporal contiguity between CS and US for the occurrence of classical conditioning. The implication was that learning involved the establishment and strengthening of an association between the CS and US as the elements of association. Against this perspective a contrary view later developed which, in seeking to promote a single paradigm subsuming both classical and instrumental (operant) conditioning, stressed the idea that Thorndike's (1898, 1911) Law of Effect could account for both types of learning. The very influential C.L. Hull (1943) was particularly emphatic in this regard, arguing strongly in favour of a single form of conditioning of the instrumental (operant) variety.

In the second instance, it will be recalled that Pavlov invoked a principle of "stimulus substitution" to account for the phenomenon of classical conditioning. A strict interpretation of Pavlov's "stimulus substitution" principle demands not only a precise topographical congruence between the CR and the UR but also that the CS should be the object of the conditioned reaction if that reaction has a directional component and the CS is localizable and contactable by the organism. The fact that early studies by Hilgard (1936) and Zener (1937) found the CR and UR to differ in a number of critical respects was thought by many to have dealt a critical blow to a "stimulus substitution" account of classical conditioning. Zener, for example, declared the CR to be anticipatory in nature, incomplete in comparison to the UR, and equivocal in its directional characteristics. Hilgard and Marquis (1940) and Kimble (1961) also argued against "stimulus substitution" theory on the basis of CR/UR dissimilarities.

In summary, Pavlov's "stimulus substitution" account of classical conditioning was thought to have been effectively discredited and although agreement was by no means universal, it seems that many were prepared to adopt an S-R account of classical conditioning under the banner of a single, fundamental process of associative learning.

The Auto-Shaping Phenomenon – A Major Anomaly with Serious Implications

The discovery of the auto-shaping phenomenon by Brown and Jenkins (1968) appears, in retrospect, to have been an event of major significance for the study of associative learning processes in animals. The term "auto-shaping" was applied to their observation that pigeons would begin to peck a key whose brief illumination over a number of trials signaled the imminent availability of food.

The demonstration that a formally Pavlovian procedure was sufficient to generate and sustain key-pecking behaviour (long considered a prototypical operant response) was not initially disturbing for it was assumed that the phenomenon relied upon a process of "superstitious" instrumental learning (Skinner, 1948). In Kuhn's terms, the auto-shaping phenomenon was acknowledged as a novelty but not one likely to escape eventual assimilation by the existing paradigm.

As evidence from a variety of research strategies began to accumulate pointing to the much greater importance of the stimulus-reinforcer, as opposed to the response-reinforcer, relationship in generating the auto-shaping phenomenon, (see reviews by Hearst and Jenkins, 1974; Schwartz and Gamzu, 1977; Mackintosh, 1974, 1983; Locurto, Terrace and Gibbons 1981; Hollis, 1982), it became clear that widely accepted views of the nature of classical conditioning (and, by implication, instrumental or operant conditioning) would need to be revised to an extent consistent with the generality of the phenomenon.

The auto-shaping phenomenon not only spurred an intensive and widespread research effort seeking to clarify its parameters but also helped to focus attention on other anomalous data which had been resistant to explanation in terms of the existing perspective (or paradigm). The challenge posed by the auto-shaping phenomenon has helped to lead the way to what Edelman (1987) has termed a conceptual shift which transcends both the original views of Pavlov and those of Skinner which had gained precedence in the intervening years. The way in which this new perspective has evolved seems to be well described by Kuhn's concept of a shift in paradigms as the driving force of progress in a science.

Behavioural Domain of Classical Conditioning – The Modern View

We have seen that Pavlov's view of the range of behaviour amenable to modification through classical conditioning was sharply curtailed by Skinner's (1938) widely accepted assertion that most motor responses had been mis-classified as respondent. The results of investigations spurred by Brown and Jenkins' (1968) discovery of the auto-shaping phenomenon have now forced many to the conclusion that Pavlov's account of the behavioural domain of classical conditioning was probably a more accurate assessment of the true state of affairs. As Hollis (1982) has noted in her review of the literature, the behavioural domain of classical conditioning would seem to extend far beyond visceral and glandular responses mediated by the autonomic nervous system to include complex, species-typical approach and locomotory behaviour, consummatory and food/water procuring behaviour, food (and poison) avoidance behaviour, inter-specific and intra-specific defence behaviour, reproductive behaviour and maternal behaviour.

In assessing the significance of the auto-shaping literature for our understanding of classical conditioning, Mackintosh (1983) speculated that the role of Pavlovian processes in the daily lives of individuals of species of intermediate phylogenetic level may be even more pervasive than Hollis has suggested:

> ... an animal's movements in space, towards stimuli or places associated with such attractive or appetitive events as the delivery of food, and perhaps away from places associated with aversive events, might be modified by purely Pavlovian procedures. If this was true, it would require a drastic reappraisal of the importance of classical conditioning, for much of the behaviour studied in the psychologist's laboratory, perhaps much of the behaviour of animals in the real world, can be thought of as approaching or avoiding places where benefit or harm will come to them, and much of what an animal must learn to survive both in the psychological laboratory and in the real world is to recognize the signs of impending events of consequence, so that appropriate approach or withdrawal can occur in anticipation of them.
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> – Mackintosh (1983, p. 7)

If Mackintosh's assertion turns out to be true, the result will not necessarily be to diminish the role of operant conditioning as a process of behavioural modification. If the behavioural domain of classical conditioning turns out to be much greater than Skinner (1938), for example, had envisioned, it is also now apparent that an absolute dichotomy between classes of behaviour in terms of their susceptibility to either classical conditioning or instrumental (operant) conditioning was, and is, a gross oversimplification of the true state of affairs.

In summarizing the evidence on this issue, Mackintosh (1983) has come to the conclusion that we must now think in terms of the relative susceptibility of a given instance of behaviour to modification by one process or the other. If responses long supposed to be operant can come under Pavlovian control (as the auto-shaping phenomenon clearly demonstrates), it is also clear that certain responses long considered to be respondent may be susceptible to modification through operant conditioning. The demonstration by Miller (1969), for example, that visceral and glandular responses may be brought under operant control set the stage for the development of biofeedback procedures (e.g., Miller, 1978) which allow voluntary control to some extent over such vital life processes as blood pressure and cardiac rate.

The extent to which reflexive (or respondent) behaviour (mediated by the autonomic nervous system) can come under operant control seems to be related to the amount of feedback the organism receives or can detect upon making the response (See Mackintosh, 1983, for a review of relevant studies). Reflexive responses such as the eyeblink are very sudden and transient, provide a minimum of feedback, and seem much more susceptible to modification through classical, as opposed to operant, conditioning. At the other extreme, responses which do not form part of the organism's reinforcer-appropriate, species-specific repertoire (i.e., pre-programmed responses to biologically significant events in the environment) and/or are rich in feedback seem to be highly susceptible to modification by operant conditioning but almost completely immune to Pavlovian contingencies.

Many responses presumably fall in between, the pigeon's key-peck providing an example. Although it is a species-typical response to food and is therefore amenable to Pavlovian control (as the auto-shaping phenomenon has demonstrated), there is some evidence to suggest that it also exhibits some sensitivity to modification by operant contingencies (Williams, 1981).

An additional possibility is that operant and Pavlovian processes may be operating simultaneously in the same situation on different aspects of behaviour. If the pigeon's key-peck or the rat's lever press is initially generated by a Pavlovian contingency, the operant contingency inherent in the situation may well "increase the economy and efficiency" of that response (Mackintosh, 1983, p. 48).

Examples of this sort of process seem to abound in the ethological literature. Eibl-Eibesfeldt (1957a, cited by Eibl-Eibesfeldt 1967) describes a situation in which an operant conditioning-like process seems to enhance the efficiency of the motor components of a species-specific, nut-opening sequence in the red squirrel. Initially, these animals possess a few "innate" motor components (gnawing and a certain splitting movement) plus an "innate" interest in nut-like objects. However, the integration of these innate components (elicited by the nut or, presumably, by any Pavlovian CS reliably associated with the nut) into an efficient, functional behavioural sequence requires a learning experience. The first attempts by young squirrels to open nuts are generally quite inefficient. A great deal of wasted effort is engendered as furrows are gnawed at random all over the nut until it finally succumbs to the squirrel's efforts. The most efficient nut-splitting technique involves the gnawing of a few strategic furrows. As more and more experience is gained, it is typically the case that fewer and fewer furrows are gnawed until, eventually, the most efficient technique emerges. This clearly seems to be a case where an operant conditioning process can refine inborn motor reaction patterns.

In short, the contemporary view of the relative behavioural domains of classical and operant conditioning transcends the earlier views held by such influential investigators as Pavlov and Skinner. The current perspective introduces the critical element of flexibility and, in so doing, provides a much better match with nature than was characteristic of either of the earlier perspectives. This amounts to a qualitative change in understanding and thus would seem to correspond rather well to what Kuhn would call a paradigmatic shift.

The Nature of the Conditioning Process – The Contemporary View

We noted earlier that the principle of stimulus contiguity was thought by Pavlov (1927) to be critical and sufficient for classical conditioning to occur. As long as a CS was paired with a US and the US elicited a UR, a CR could be expected to emerge to CS presentations at some point in the conditioning process. However, more recent evidence insists that the situation is much more complex than Pavlov seems to have imagined.

The modern view of the nature of the conditioning process is far removed from a simple principle of stimulus (CS-US) temporal contiguity. The evidence is now overwhelming that conditioning is not an automatic and inevitable consequence of a temporal overlap between CS and US. Many factors are now known to affect the probability and course of conditioning (See Mackintosh, 1974, 1983 for a review of these studies). These include US intensity and probability, CS salience and quality (its sensory and/or motivational aspects), the temporal relationship between CS and US, and CS-US relevance (some organisms seem predisposed to associate certain sub-classes of stimuli in preference to others as the taste aversion studies of Garcia and Koelling, 1966, were the first to demonstrate).

One of the most important considerations, and perhaps the most critical, is the predictive validity (the information value) of the CS via à vis the US. The predictive value of the CS relates both to its past relationship with the US and its present relationship to other stimuli that may also predict the US with a certain degree of reliability. Kamin (1969) and Wagner (1969a) emphasize the relative, as opposed to the absolute, predictive validity of the CS as the critical determinant of the probability and course of conditioning. Both Rescorla (1975) and Dickenson (1980) emphasize CS novelty as a critical precursor to the occurrence of conditioning.

In summary, the conditioning process is now perceived to be dependent on a complex of factors which ultimately relate to the relative predictive validity of the CS. As Hollis (1982) suggests in her "pre-figuring" hypothesis, classical conditioning is essentially a process for reducing the capriciousness of the environment by guiding and directing an organism's behaviour in such a way that interaction with the impending biologically significant event (the US) is optimized. From this point of view, classical conditioning is likely to occur only to the extent that the CS reliably and uniquely predicts the occurrence of the US. Put another way, it would seem that an organism develops an expectancy as a consequence of classical conditioning and this expectancy, triggered by an encounter with the CS, results in behaviour (the CR) which prepares the organism for its impending encounter with the US (Staddon, 1983).

The contemporary view of the conditioning process represents a major departure from the earlier assertion that CS-US temporal contiguity is the necessary and sufficient condition for conditioning to occur. In this sense it represents another example of a qualitative change in thinking akin to what Kuhn would call a paradigmatic shift.

With respect to a "stimulus substitution" acccount of classical conditioning, it is clear that the results of many studies, especially those in the auto-shaping vein, are well described by even a strict interpretation of the principle originally stated by Pavlov. Of many possible examples, perhaps the best is to be found in the experiments of Jenkins and Moore (1973) who employed food and water reinforcers (USs) with pigeons in an auto-shaping context. The responses (CRs) directed at the signals for food and water clearly differed in topography, each response being appropriate to the reinforcer (US) being signaled. It was as if, in colloquial fashion, their pigeons attempted to "eat" the stimulus object signaling food and "drink" the stimulus object signaling water. The demonstration by Rackham (1971, 1977) that male pigeons will come to direct species-typical courtship behaviour at a stimulus object reliably signaling imminent access to their mates is another example of an outcome that is well described by even a strict reading of the original "stimulus substitution" principle.

In contrast, there are many situations in which clear topographical differences exist between the CR and the UR (See, reviews by Mackintosh 1974, 1983; Hollis, 1982; among others). Moreover, the CR may not be directed at the CS object as a strict reading of the "stimulus substitution" principle would seem to require. Despite such evidence, Mackintosh (1974) was still able to come to the conclusion that rejection of "stimulus substitution" theory may have been premature. His plea for a "more careful and extensive analysis of the range of responses elicited by appetitive and aversive reinforcers under various conditions" (p. 109) has subsequently been met to a major degree. This had led, in turn, to a major change in perspective (an apparent shift in paradigm) in which the form and directionality of the CR and UR are seen to be influenced by a whole host of factors.

Evidence now available from a wide variety of sources strongly suggests that the UR consists not simply of a single, stereotypical response but a range of responses, only a subset of which may appear under any given set of conditions. As Hollis (1982) puts it, the CR "is not one but actually a battery of responses, both autonomic and skeletal, some similar to the UR and some opposite in direction, but together as one unit they function to insure optimization of biologically relevant events." (p. 5). Mackintosh (1983) suggests that the CR is best considered to be an index of learning, but not an absolute index. It is now apparent that the sensory and motivational properties of both the CS and US are the critical determinants of what will be actually emerge in a given conditioning situation.

If the "stimulus substitution" principle is interpreted in more liberalized terms, then a range of possibilities regarding the extent of CR/UR topographical overlap and directionality of conditioned behaviour is admitted, including those situations where even a strict reading of the doctrine will suffice to describe the observed behaviour (e.g., Jenkins and Moore 1973; Rackham, 1971, 1977).

It is sufficient to note here that the parameters likely to affect the degree of CR/UR topographical overlap and CR directionality include the nature of the CS (including its sensory properties and localizability, its relative predictive validity, and the environmental support it provides for a CR with a directional component), the nature of the US (including its intensity, sensory and motivational properties, and the point in the appetitive/consummatory sequence at which it is introduced), spatial and temporal relationships between the CS and US, and any instrumental (operant) contingencies in effect in the situation (See Mackintosh, 1983 for a review of the evidence relating to these factors).

This means, in practice, that the CR and UR may be very similar in form, or radically different in form, drawn from the same response system, or different response systems, in the same direction, or opposite in direction (as a compensatory reaction to the effects of the US). This also means that the CR may be directed at the CS site, US site, intermediate sites, or lack any obvious directional characteristics. However, what binds the CR to the UR is ultimately the fact that the CR is not a random response but a response drawn from, and constrained by, the species-typical behavioural repertoire appropriate to the reinforcer (US). This provision and constraint must, in the end, represent the central tenet of any liberalized version of the "stimulus substitution" principle.

In its ability to accommodate a wide range of anomalous data, while simultaneously constraining the relationship between CR and UR, a liberalized version of the "stimulus substitution" principle represents an evolution in thinking which is both quantitative and qualitative in nature. To the extent that the liberalized version of this principle is qualitatively diferent from the version originally provided by Pavlov, we have seen a paradigm shift such as Kuhn (1970) argues is critical to progress in science.

Summary and Conclusions

Over the past half century or so, a revolutionary change has occurred in the way theorists have viewed classical conditioning as an adaptive process of behavioural modification. The major tenet of this paper has been that this evolution in thinking about the behavioural domain of classical conditioning and the very nature of the conditioning process, itself, has involved a series of conceptual shifts of potentially revolutionary proportions. While it has not been possible to explore the subtleties of these conceptual shifts in great detail, the overall picture seems to conform rather well to the sort of account which Kuhn (1970) offered of the nature of progress in a scientific endeavour.

For Kuhn, progress in science is driven by periodic breakdowns in existing paradigms which, unable to accommodate anomalous data in a satisfactory manner, are replaced by new paradigms in a process akin to a revolution. Paradigms survive to the extent that they are compatible with the evidence which nature presents. The traditional paradigms associated with classical conditioning have been found wanting and a new view, a new paradigm, seems to have emerged which transcends any of its predecessors.

Once considered the most elementary and, perhaps, the least significant of the various processes of associative learning, classical conditioning is now seen as a much more sophisticated and flexible form of behavioural adaptation to the environment. The revolution in thinking about classical conditioning, at least with respect to organisms of intermediate phylogenetic level, has turned on two basic themes – (1) the behavioural domain of classical conditioning, and, (2) the very nature of the conditioning process, itself.

It is now generally conceded that the behavioural domain of classical conditioning is much more pervasive than Skinner (1938), for example, originally believed. Among the major catalysts (or anomalies) leading to this revelation was the auto-shaping phenomenon of Brown and Jenkins (1968). In the process of dealing with the challenge to existing views posed by this phenomenon, it has become apparent that it is no longer appropriate to think of a response as being susceptible to modification exclusively by one form of conditioning or the other. A given response should be considered to lie on a continuum which ranges from behaviour susceptible to modification exclusively by classical conditioning to behaviour modifiable exclusively by operant conditioning. Depending on its location along this continuum, a response may be more or less susceptible to modification by both types of learning process. This is a qualitative change in perspective which obviously contrasts sharply with the former, widely accepted notion of a rigid dichotomy between respondent and operant behaviour on the basis of such distinctions as autonomic/skeletal or involuntary/voluntary. In this sense, it represents the product of a revolutionary process such as that described by Kuhn (1970).

With regard to the nature of the conditioning process, itself, it is clear that classical conditioning can no longer be viewed as a simple and inevitable consequence of temporal overlap between a CS and a US. Staddon (1938) has defined learning, including classical conditioning, as an acquired change in behaviour (or behaviour potential) which links the present to the past in a manner which usually serves the adaptive needs of the individual. Mackintosh (1983) has recently been moved to suggest that "... conditioning is most profitably viewed as the acquisition of knowledge about relations between events and the change in behaviour recorded by the experimenter best treated as an index of that knowledge." (p. 12).

Elaborating on this view, Mackintosh proposes that conditioning "involves the acquisition of new knowledge about the world, the mapping of relationships between events of significance to the individual so that the individual can respond to significant events in a biologically adaptive manner." Statements such as these clearly suggest that there has been a major revolution in the way theorists are thinking about the nature and adaptive significance of classical conditioning.

As Thomas Kuhn might say, there has been a Gestalt-like shift in our understanding of the conditioning process, a shift to a new paradigm which provides a much better match to nature than was previously available. Perhaps the final word may be left to the Nobel Laureate, Gerald M. Edelman, who, in a recent volume entitled *Neural Darwinism: The Theory of Neuronal Group Selection*, points to the conceptual shift which has occurred in our understanding of the nature of conditioning. In Edelman's words, "while the basic paradigms of classical and operant conditioning remain robust... the interpretation of their significance has changed. The old view that the contiguity and precedence relations of a conditioned stimulus and an unconditioned stimulus are sufficient has had to be abandoned.... Contiguity of stimuli is not the major issue in learning; rather, it is the correlation of context with the predictive value of the conditioned stimulus that is significant. This leads to the important conclusion that an animal in a species develops a representation of knowledge of a learning situation on the basis of differential expectancies; that is, certain stimuli show stronger interactions than others (1983, p. 293).

References:

Barnett, S. (1962) The expression of the emotions. In S. A. Barnett (Ed). *A Century of Darwin.* London: Mercury Books, 1962, pp. 206-230.

Brown, P. and Jenkins, H. (1968). Auto-shaping of the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior*, 11, 1-8.

Dickenson, A. (1980). *Contemporary Animal Learning Theory*, Cambridge: Cambridge University Press.

Edelman, G. (1987). *Neural Darwinism: The Theory of Neuronal Group Selection.* New York: Basic Books.

Eibl-Eibesfeldt, I. (1967). Concepts of ethology and their significance in the study of human behavior. In H. Stevenson and H. Rhenfold, eds. *Early Behavior.* New York: Wiley.

Garcia, J. and Koelling, R. (1966). Relation of cue to consequence in avoidance learning. *Psychonomic Science*, 4, 123-124.

Hearst, E. and Jenkins, H. (1974). *Sign-Tracking: The Stimulus-Reinforcer Relation and Directed Action.* Austin, Texas: The Psychonomic Society.

Hilgard, E. (1936). The nature of the conditioned response. I. The case for and against stimulus substitution. *Psychological Review*, 46, 366-385.

Hilgard, E. and Marquis, D. (1940). *Conditioning and Learning.* New York: Appleton-Century-Crofts.

Hollis, K. (1982). Pavlovian conditioning of signal-centered action patterns and autonomic behaviour: a biological analysis of function. In J. Rosenblatt, R. Hinde, C. Beer and M. Busnel (Eds.) *Advances in the Study of Behavior, v. 12.* New York: Academic Press, pp. 1-63.

Hull, C. (1943). *Principles of Behavior.* New York: Appleton-Century-Crofts.

Jenkins, H. and Moore, B. (1973). The form of the auto-shaped response with food or water reinforcers. *Journal of the Experimental Analysis of Behavior.* 20, 163-181.

Kamin, L. (1969). Selective attention and conditioning. In N. Mackintosh and W. Honig, eds. *Fundamental Issues in Associative Learning.* Halifax: Dalhousie University Press, pp. 42-64.

Kimble, G. (1961). *Hilgard and Marquis' Conditioning and Learning.* New

York: Appleton-Century-Crofts.

Kuhn, T. (1970). The Structure of Scientific Revolutions (2nd Edition). Chicago: The University of Chicago Press.

Locurto, C., Terrace, H., and Gibbons, J. (Eds.) (1981). *Autoshaping and Conditioning Theory.* New York: Academic Press.

Lorenz, K. (1965). *Evolution and Modification of Behavior.* Chicago: University of Chicago Press.

Mackintosh, N. (1974). *The Psychology of Animal Learning.* London: Academic Press.

Mackintosh, N. (1983). *Conditioning and Associative Learning.* Oxford: Oxford University Press.

Miller, N. (1969). Learning of visceral and glandular responses. *Science,* 163, 434-445.

Miller, N. (1978). Biofeedback and visceral learning. *Annual Review of Psychology,* 29, 373-404.

Miller, S. and Konorski, J. (1928). Sur une forme particuliere des reflexes conditionnels. *Les Comptes Readus des Seances de la Societé de Biologie, Societé Polonaise de Biologie,* XCIX, 1155. Translated by B. Skinner in *The Journal of the Experimental Analysis of Behavior,* 1969, 12, 187-189.

Pavlov, I. (1927). *Conditioned Reflexes.* Oxford: Oxford University Press.

Pavlov, I. (1930). A brief outline of the higher nervous activity. In C. Murchison (Ed.) *Psychologies of 1930.* Worcester, Mass.: Clark University Press, pp. 207-220.

Pavlov, I. (1934). An attempt at a physiological interpretation of obsessional neurosis and paranoia. *Journal of Mental Science,* 80, 187-197.

Rackham. D. (1971). Conditioning of the pigeon's courtship and aggressive behaviour. Unpublished M. A. Thesis, Dalhousie University, 1971.

Rackham, D. (1977). Discriminative courtship conditioning in the pigeon, *Columba livia.* Unpublished Ph. D. Dissertation, Dalhousie University.

Rescorla, R. (1975). Pavlovian excitatory and inhibitory conditioning. In W. Estes, ed. *Handbook of Learning and Cognitive Processes, v. 2.* Hillsdale, New Jersey: Lawrence Erlbaum, pp. 7-35.

Schwartz, B. and Gamzu, E. (1977). Pavlovian control of operant behavior.

In W. Honig and J. Staddon (Eds.) *Handbook of Operant Behavior.* Englewood Cliffs, New Jersey: Prentice-Hall, pp. 53-97.

Skinner, B. (1938). *The Behavior of Organisms.* New York: Appleton-Century-Crofts.

Skinner, B. (1948). Superstition in the pigeon. *Journal of Experimental Psychology,* 38, 168-172.

Spalding, D. (1873). Instinct with original observations on young animals. *Macmillan's Magazine,* 27, 282-293. (Reprinted in the *British Journal of Animal Behaviour,* 1954, 2, 2-11).

Staddon, J. (1983). *Adaptive Behavior and Learning.* Cambridge: Cambridge University Press.

Thorndike, E. (1898). Animal intelligence: an experimental study of the associative process in animals. *Psychological Monograph 2.*

Thorndike, E. (1911). *Animal Intelligence: Experimental Studies.* New York: Macmillan.

Wagner, A. (1969a). Stimulus validity and stimulus selection in associative learning. In N. Mackintosh and W. Honig, eds. *Fundamental Issues in Associative Learning.* Halifax: Dalhousie University Press, p. 90-122.

Watson, J. (1925). *Behaviorism.* New York: Norton.

Williams, D. (1981). Biconditional behavior: conditioning without constraint. In C. Locurto, H. Terrace, and J. Gibbon, eds. *Autoshaping and Conditioning Theory.* New York: Academic Press, pp. 55-99.

Zener, K. (1937). The significance of behavior accompanying conditioned salivary secretion for theories of the conditioned response. *American Journal of Psychology,* 50, 384-403.