ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol. Exp. 1996, 56: 469-484

Preliminary process theory: towards an integrated account of the psychophysiology of cognitive processes

Robert J. Barry

Department of Psychology, University of Wollongong, Wollongong 2522, Australia

Abstract. A brief overview of the history of the orienting reflex (OR) in western psychology is presented, in order to provide a context for a discussion of its role in attentional processing. Some aspects of observed response fractionation are discussed, leading to an outline of a coherent theory of preliminary processes in OR elicitation. This discriminates between involuntary and voluntary aspects of cognitive processing but depends on a common core mechanism. The role of state variables in modulating phasic responses is also discussed. Although this theory was developed largely from a study of autonomic responses, it has been possible to extend it to include various central measures, and recent extensions are described. A number of recent studies are briefly outlined to provide examples demonstrating the use of a range of physiological measures (central and peripheral) in a variety of situations (from the pistol range to the laboratory) with different subject groups (adults, children and psychiatric patients). Finally, the use of heart rate data in the investigation of task-relevant cognitive load is discussed as a relatively simple but sensitive index to explore drug and other effects in cognition. These examples indicate the wide-ranging potential benefits of using psychophysiological approaches in the study of cognitive processes.

Key words: cognition, psychophysiology, attention, vigilance, signal value, orienting reflex, preliminary process theory, evoked cardiac response, electrodermal activity, electroencephalography, event-related potentials

Review

INTRODUCTION

This paper presents an overview of a research program in cognitive neuroscience directed at establishing a coherent account of the phasic and tonic physiological activity associated with a range of cognitive processes. Its major emphasis has been on autonomic functioning in the context of the orienting reflex (OR), originally noted by Ivan Pavlov in 1910 as the "What is that?" reflex. Initially focused on the turning or orienting of the organism towards a novel stimulus, this discovery began an important saga in the development of our current knowledge of psychophysiology.

Although Pavlov made his initial discovery of the OR in 1910, little detail was known of this phenomenon in the west, beyond its behavioural aspects, until approximately 1960. During this period of some fifty years, a great deal of theoretical development occurred in Russia as scientific attention broadened knowledge of the reflex from its initial conceptualization (as a whole body, organismic response of the animal to a novel stimulus) to an examination of its physiological and psychological correlates. Unfortunately, because of the cold war, much of this knowledge did not reach western awareness.

The current dominant theory of the OR is that of Sokolov (1963), the Russian whose work led to popularization of the OR in western scientific literature. He presented the OR as a major phenomenon in both learning and perception. The characteristics of the OR elaborated by Sokolov logically led to its identification as the unit of attentional processing. Subsequent work in my laboratory on aspects of response fractionation in the OR context has developed a theory of preliminary processes in OR elicitation which moves beyond the unitary theoretical structure developed by Sokolov.

The majority of recent work in this area has focused upon the phasic aspects of stimulus processing, but an integration with tonic measures of state would be expected to hold promise. Unfortunately, concepts of arousal and activation fell into disrepute when fractionation of the putative arousal indices was noted. It is my thesis that we should accept that the traditional unitary arousal concept was overly simplistic and return to the study of such tonic indices. We should attempt to integrate them with phasic indices of attentional processing in order to expand our explanatory power. To this end, an expanded version of preliminary process theory, which begins such an integration, is presented. It is illustrated by selected recent examples of our studies, which indicate the benefits of using such an integrated psychophysiological approach to the study of cognitive processes.

THE ORIENTING REFLEX

Defining characteristics

The Sokolovian, or what are now called "classical", notions of the orienting reflex will be outlined briefly here. What is it about a stimulus event that affects the elicitation of the orienting reflex? Sokolov focused on three of these determinants - novelty (or the "newness" of the stimulus), intensity, and significance.

The novelty of a stimulus is operationalised in terms of its decrease with stimulus repetition, i.e., as we repeatedly present a stimulus, its novelty decreases. If we repeatedly present a person or an animal with a stimulus, as its novelty decreases, so also does the magnitude of the orienting reflex that the stimulus elicits. With repeated stimulus presentations, the magnitude of the orienting reflex decreases exponentially and approaches some asymptotic base level. This decremental process is referred to as habituation. In common practice, some 12 to 15 stimulus repetitions are sufficient for the response to die away, almost to zero. This decremental process is selective, since if we present a slightly-different stimulus, a large orienting reflex is produced. This distinguishes habituation from other decremental processes such as fatigue.

Groves and Thompson (1970) have provided formal criteria for habituation which encompass and elaborate these stimulus-response relations. We expect exponential response decrement with stimulus repetition, and response recovery to a novel change stimulus. In addition, subsequent presentations of the original stimulus evoke larger responses than those prior to the change stimulus, a phenomenon referred to as "dishabituation".

With intensity, the picture is more complex. In a moderate range of innocuous stimulus intensities, the magnitude of the orienting reflex is linearly related to intensity - if we increase stimulus intensity, so also does the magnitude of the response increase. At high intensities, at the prepain zone (where the stimulus intensity is so great as to be on the verge of eliciting pain), we get a different reflex form occurring. This response to noxious stimuli is called the defensive reflex and was seen by Sokolov as functioning to protect the organism - it begins to limit the effects of the stimulus, effectively shutting down the sensory system. For various reasons, primarily concerned with ethical considerations, the defensive reflex has not been studied extensively in the west. We know little of its determinants or characteristics. At low intensities there is an apparent enhancement of the reflex intensity at stimulus magnitudes near threshold.

The third determinant of the orienting reflex examined by Sokolov was stimulus significance. Effects of stimulus significance are apparent where a stimulus has outcomes beyond those associated with the physical characteristics of the stimulus alone. A simple example is that if you are scanning a list of words, and your name is a member of that list, then you produce a larger response to that. This also occurs with conditioned stimuli. We can also attach significance to a stimulus by the use of instructions. For example, if I ask an experimental subject to "attend to the high pitch tone" or to "press a button when the light occurs", then those stimuli will elicit a larger response than they would have prior to the instruction.

Mechanism

Sokolov's mechanism involves a neuronal model and a stimulus comparator. The neuronal model of the stimulus is developed in the cortex with repeated stimulus presentations. According to Sokolov, an incoming stimulus is compared with the model of the stimulus that has been built up during previous presentations. The discrepancy between the actual stimulus and the model generates the orienting reflex. From this perspective, the first presentation of the stimulus occurs in a context where there is no model. It is entirely unexpected, novel, and the maximum OR is generated. At the second presentation, a rough model has been formed from the first presentation, so in comparison, the discrepancy between the model and the stimulus is reduced, and we get a smaller orienting reflex. When this is continued until about (say) the 10th, 12th or 15th presentation, the cortex has established an almost-exact model of the stimulus and we get an almost-zero orienting reflex. Intensity effects are handled in this model via an amplifying function, so that the model-comparator output is multiplied by an amplifying function to produce the observed orienting reflex.

Measures

Sokolov claimed many physiological and behavioural responses showed the above characteristics. These included the galvanic skin response (GSR), respiratory pause, reciprocal blood volume changes in the head and fingers, EEG alpha desynchronisation, pupil dilation, eye movements, changes in position of the body, and heart rate changes. Sokolov considered the orienting reflex as a unitary phenomenon, in which a broad range of such physiological and behavioural measures show a similar pattern over variations in stimulus parameters. In his writings he referred only to the OR in this singular sense.

Response fractionation

Barry and James (1981a) reported the outcomes from a simple paradigm used to test Sokolov's unitary theory that a range of physiological measures would covary in relation to stimulus manipulation. We presented our subjects with simple visual stimuli, either large squares or small squares, presented on a video display unit. Each stimulus was presented for 2 s. and there was a period of from 40 to 60 s. between stimuli. One group was presented with 10 large squares followed by a small square (the change stimulus), and then 5 of the original large squares. The other group had the small and large squares interchanged. By using two groups we could investigate between-group differences as a function of stimulus magnitude.

We carried out our investigation using four physiological measures: electrodermal activity (or the galvanic skin response, GSR), heart rate deceleration, respiratory pause and peripheral vasoconstriction in the finger. With this experimental design we expected, from Sokolov's unitary theory, that all the measures would covary and show response decrement to stimulus repetition, response recovery to the change stimulus, dishabituation following the change stimulus, and an intensity or stimulus energy effect with the larger stimuli. This pattern is indicated in Fig. 1, where, for simplicity, the intensity effect is shown only over the first 10 stimuli.

In fact only the electrodermal response showed this pattern. In contrast, with the cardiac response, we had no stimulus effects whatsoever. At every stimulus presentation, a similar heart rate deceleration occurred, regardless of the repetition or intensity of the stimulus. With respiratory pause, we

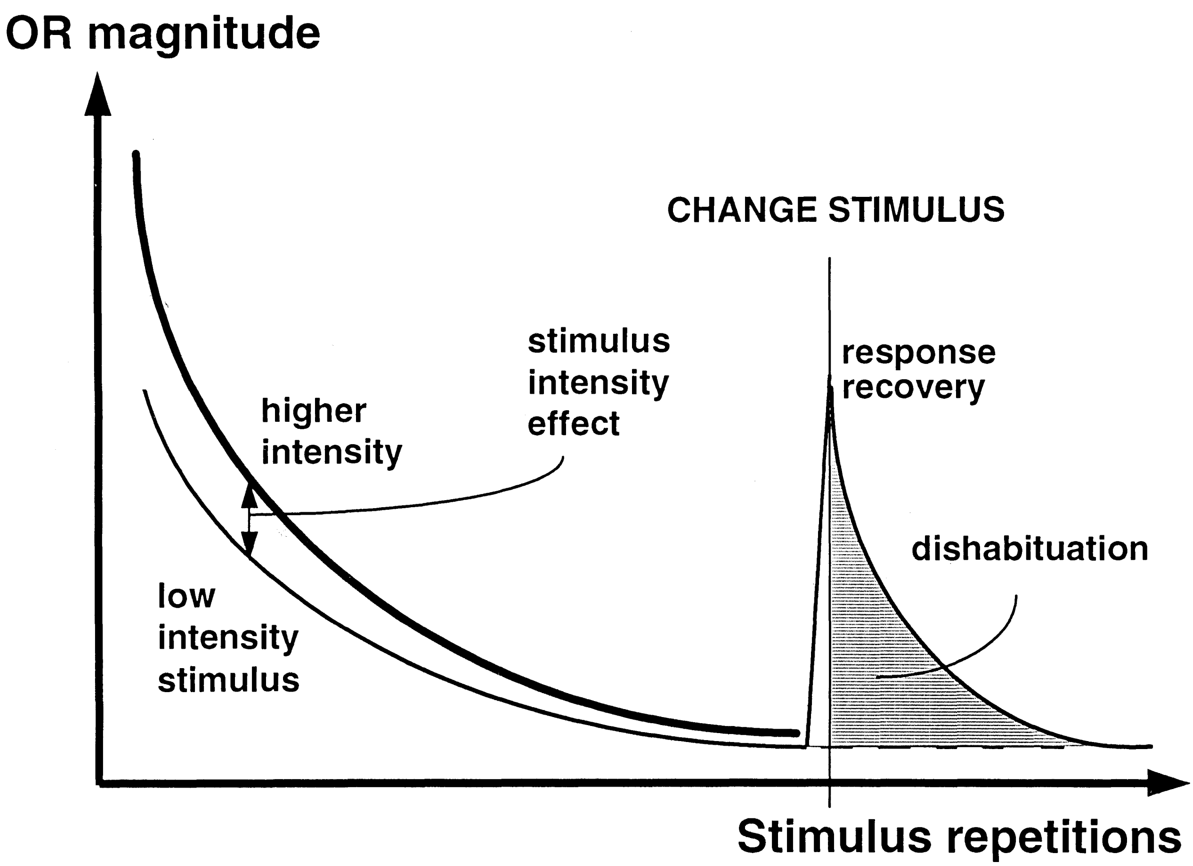

Fig. 1. The model OR as a function of stimulus repetitions: response decrement occurs until the change stimulus, which produces response recovery. Subsequent presentations of the original (pre-change) stimulus initially produce enhanced responding (dishabituation). There is also a stimulus intensity effect - enhanced responding to a higher-intensity stimulus - shown only over the pre-change stimulus presentations for simplicity.

found only response decrement and recovery; there was no evidence of dishabituation and no intensity effect. The peripheral pulse amplitude response of vasoconstriction was found to show a substantial intensity effect, with the larger squares eliciting larger responses, but there was no decrement in this response with stimulus repetition. These different stimulus-response patterns are shown schematically in Fig. 2.

Clearly, the four measures showed different relations with stimulus parameters. This was a disconfirmation of Sokolov's unitary OR theory and illustrates response fractionation in OR measures, splitting-up Sokolov's unitary response. This pattern of results was not unexpected. Previously, I had observed, over a number of years, that there were substantial discrepancies between expectations of a unitary construct and our experimental results (e.g., Barry, 1977a,b, 1978, 1979). Barry and James (1981a) simply provided a case study of this fractionation.

PRELIMINARY PROCESS THEORY

The reliability of this type of response fractionation led me to propose, as an alternative to Sokolov's unitary theory, what is now called preliminary process theory. This is an attempt to give a coherent account of the observed fractionation of orienting reflex components, similar to that which we reported in the Barry and James (1981a) study. Over

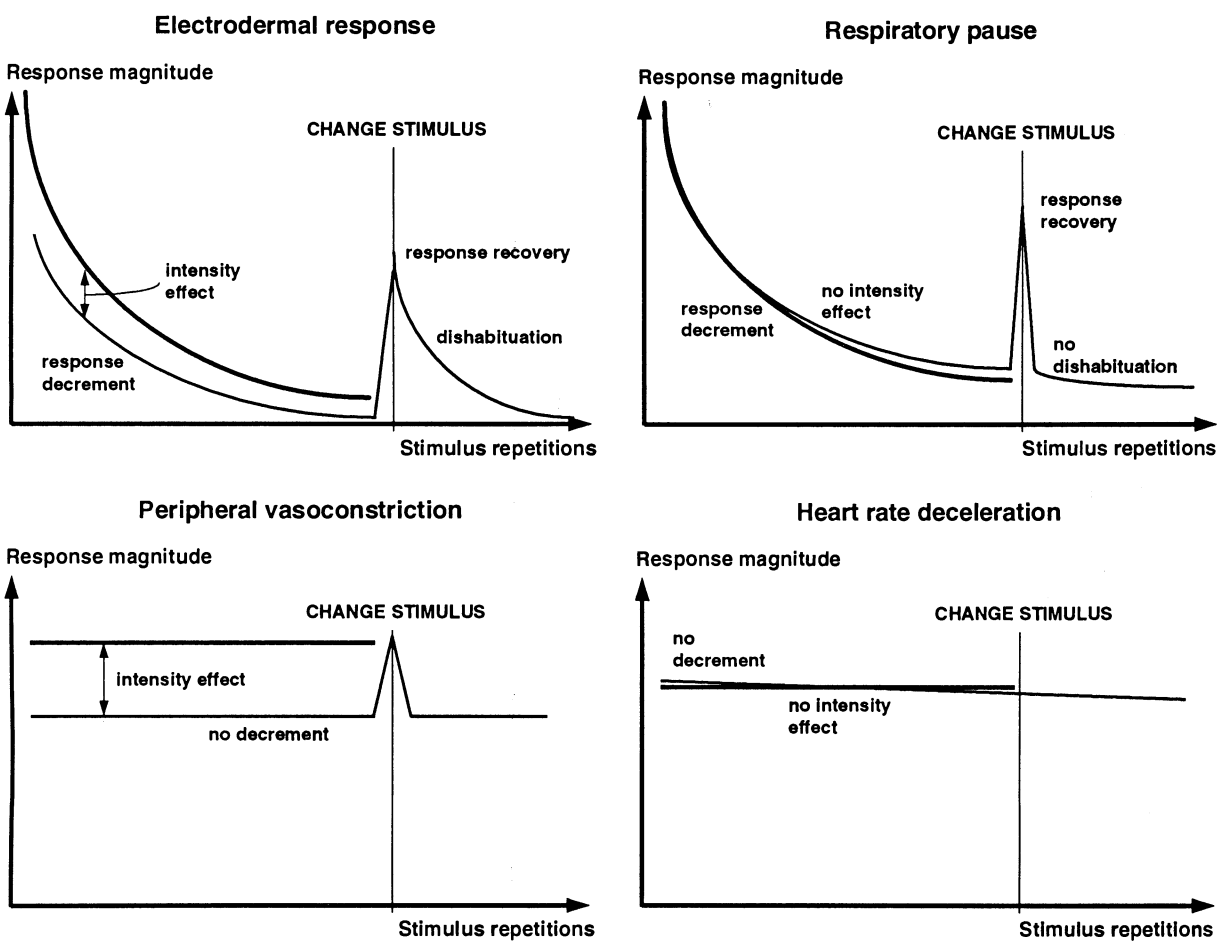

Fig. 2. A schematic representation of the results of Barry and James (1981a). The figure indicates response fractionation in four physiological measures as a function of stimulus novelty and intensity.

the years, the original simple model has developed in numerous ways, which have been described elsewhere (Barry, 1984, 1987a,b, 1990). Essentially this theory sees different processing stages innervating the physiological measures separately rather than in the unitary fashion proposed by Sokolov. This theoretical schema is shown in Fig. 3 and described below.

The initial processing stage is triggered by the occurrence of the stimulus qua stimulus, and functions on an all-or-none basis regardless of the parameters of the stimulus. Its triggering indicates that the organism has detected or registered the stimulus, although this does not imply conscious awareness. This process begins the sequential processing of the stimulus characteristics and innervates cardiac deceleration, labelled ECR1 (the first evoked cardiac response to the event). The output of this stage triggers the separate processing, in parallel, of stimulus novelty and magnitude. Processing of novelty is reflected in respiratory pause (RESP), while the extent of stimulus magnitude processing is apparent in peripheral vasoconstriction (the peripheral pulse amplitude response, PPAR). The outcomes of these parallel processes multiply to generate the orienting reflex, apparent in the electrodermal response, or GSR. This ordering of the processes is the only sequence logically allowed by the data. The model was originally presented in Barry and James (1981a).

The mechanism of this processing parallels the dual-process theory of habituation proposed by Groves and Thompson (1970), so-called because it involves two hypothetical processes. One of these, the "habituation" or H process, is a neural pathways effect, in which decrement occurs with stimulus

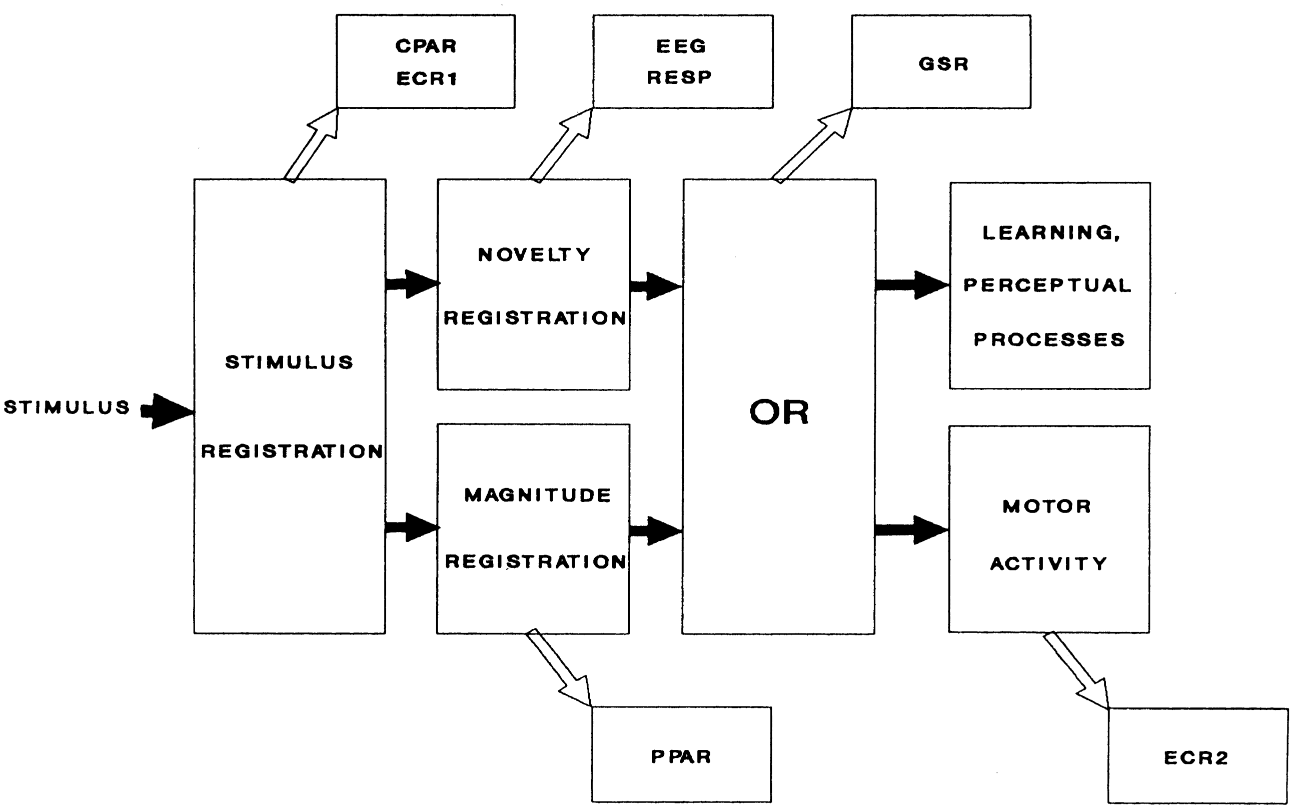

Fig. 3. An outline of preliminary process theory for indifferent stimuli. The figure indicates the sequential processes hypothesized to separately innervate the response measures shown. Physiological responses: ECR1, HR deceleration; CPAR, cephalic vasodilation; EEG, EEG alpha desynchronisation; RESP, respiratory pause; GSR, galvanic skin response; PPAR, peripheral vasoconstriction; ECR2, HR acceleration.

repetition. This pathways effect is relatively insensitive to stimulus intensity. Their second process is "sensitisation" or S, a state effect. This process shows an initial increase with stimulus repetition, then a return to baseline, but it is very sensitive to stimulus intensity. The outcomes of these two processes, H and S, are multiplied to generate the orienting response. These hypothetical non-cortical processes are appealing on parsimony grounds, compared with the more-complex Sokolovian cortical mechanism of OR elicitation and habituation described above, and were first incorporated into the model in Barry and James (1981b). H is identified with the novelty registration process, and S with the intensity processor.

One of the three determinants of the orienting reflex developed by Sokolov was the significance of the stimulus. In the presentation above, I have been concentrating upon non-significant, or so-called "indifferent", stimuli, and their associated responses, which are involuntary reflexes. This needs to be extended by including a mechanism to accommodate the switching and enhancement of attention with instructions - an additional mechanism is necessary to allow us to interleave the reflexive process that we've been discussing with higher aspects of attentional processing. One approach is to add a voluntary control mechanism to the involuntary reflex process - essentially a steering mechanism. A useful mechanism in this context is that of cortical set. Cortical set is derived from the general concept of "set" which has a long history in psychology. This newer concept is supported by Livanov's (1977) examination of the coherence of EEG brain-wave patterns over the scalp, and the determination of how activity at different sites is related, indicating the involvement of different underlying brain structures in different tasks. So we have been able, through Livanov's work, to move from a vague traditional concept of "set", to an operationalised notion of "cortical set", brought to western attention by Irving Maltzman (1979). He proposed a volun-

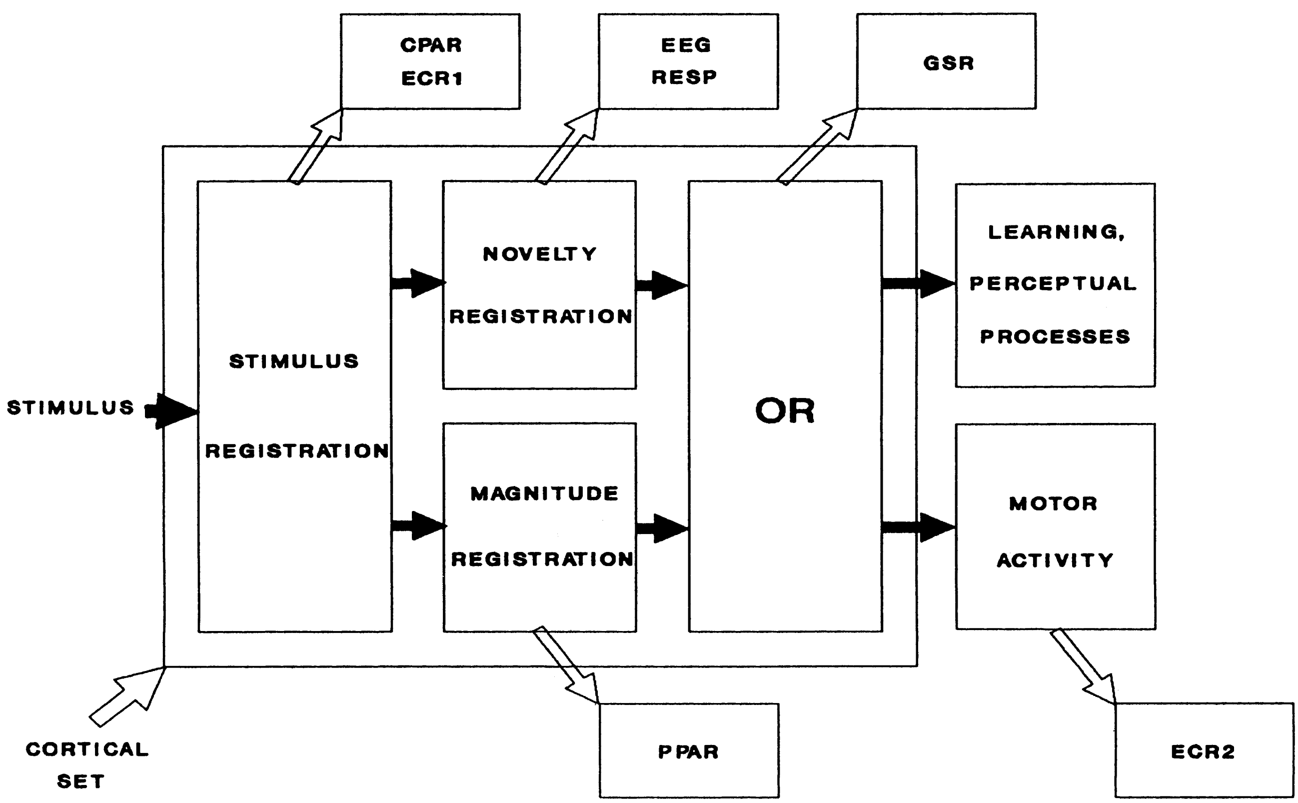

Fig. 4. Preliminary process theory with cortical set. Cortical set functions as an attentional steering mechanism, which can have differential outcomes on the response components, depending on the locus of the effect.

tary orienting reflex which accommodates both cognitive and higher mental functions. "Voluntary" in this sense is used to indicate that the cortical set of the individual is able to be modified in anticipation of events requiring attentional processing, as compared with the involuntary reflex which automatically switches attention. This principle of a voluntary OR, operationalised through cortical set, is used as a steering mechanism in preliminary process theory. With the addition of this mechanism, the orienting reflex, in both its involuntary reflex and voluntary response form, can be seen to be fundamental to a wide range of attentional processes, and very important in the modulation of our interaction with the environment. The model incorporating steering by cortical set is shown in Fig. 4.

Different forms of attentional demand, requiring different forms of cortical set, have been able to be teased out by considering the effects of the sequential processing at the core of preliminary process theory. For example, if we present a subject with a series of stimuli varying in some attribute, such as a number of tones differing in intensity (within the innocuous range), the effects of a variety of instructions can be considered. The responses obtained under indifferent instructions, as noted above, would represent the preliminary processes associated with the simple involuntary OR. If we request the subject to make a speeded reaction-time response to each tone, regardless of its intensity, we have a simple manipulation of vigilance. The subject can specifically alter his/her cortical set to anticipate the occurrence of the stimuli and to prepare to emit a speeded response when a tone onset is detected. This preparatory activity in anticipation of the stimulus will result in a general non-specific enhancement of all aspects of the sequential processing of the stimulus in comparison with those observed under indifferent conditions.

In contrast, if we ask the subject to discriminate some of the stimuli on the basis of one of the stimulus characteristics, such as intensity, and to respond accordingly, we have a manipulation of signal value. In this case, differential enhancement of some of the indicators of the processes involved in the sequential processing of the stimulus will occur. In particular, we can predict that there will be no differential effect of the instruction on any process prior to the discrimination phase, but that the stage involved in processing the discrimination, and subsequent processing stages, will show differential enhancement in the response measures innervated by them. For example, if we require a speeded reaction time response to a stimulus class of a certain intensity or magnitude, then the physiological indices of the stimulus magnitude processing subsystem, and indices of the subsequent OR processing stage, will show selective enhancement to the target stimuli in comparison to the responses shown to the non-target stimuli. This differential involvement of specific processing stage indices, as a function of vigilance *versus* signal value manipulations, has been confirmed in a study by Barry (1988). It should be pointed out that such differential predictions cannot be made in the absence of a sequential processing theory of OR elicitation.

One interesting observation is that requiring a response to a stimulus results in a second evoked phasic cardiac response component (ECR2) of HR acceleration in addition to the decelerative ECR1 mentioned above. Depending on the manipulation and the component latency, this may either result in an overall accelerative HR response or a biphasic (deceleration followed by acceleration) response. The former is usually observed when a prepared physical response (such as is associated with a speeded simple reaction time task) is involved. The latter can be seen reliably if the subject is involved in a cognitive task related to the stimulus. The simplest example of this is if the subject is asked to covertly count (sequentially) the number of stimuli presented. In such a case, the ECR2 component can be observed to increase over trials, which has been taken to indicate the effect of increasing cognitive load. The biphasic evoked cardiac response complex is thus a potential source of information regarding both the registration of a stimulus (ECR1) and the extent to which it is cognitively processed (ECR2).

Other physiological measures have been added to this model. For example, the cephalic pulse amplitude response (CPAR) of vasodilation also can be taken to index the initial stage of stimulus registration, since it occurs reliably at stimulus onset yet fails to show either stimulus intensity or novelty effects. EEG alpha desynchronisation can be taken as an index of the processing of novelty, since the extent of desynchronisation decreases reliably with stimulus repetition without displaying stimulus intensity effects. The reader can examine Barry (1982) for examples of the findings which support these placements of the physiological indices within the theoretical sequential processing.

It should be noted that in preliminary process theory, the output orienting reflex still retains the functionalism of Sokolov's orienting reflex - i.e., the role of the OR in perception and attention proposed by Sokolov is still accepted. Unfortunately, there has not been the widespread interest in developing this aspect of Sokolov's conceptualization that might have been expected from its central importance in behavioural science. At least part of this slow development can be traced to the problems in the literature with the fractionation of phasic responses associated with the OR in Sokolov's writings, and the uncertainty which this generated regarding the reliable measurement of the OR as an independent variable for use in further research.

AROUSAL/ACTIVATION - STATE MEASURES

Background

The basic historical concept of state is that arousal or activation amplifies our on-going behaviour. From this perspective, if we plot behavioural efficiency against arousal or state level, we expect to find what is called an "inverted-U" function. That is, as we gradually increase arousal or activation, behavioural efficiency first increases, directly proportional to that arousal increase. However, if we continue, the behavioural efficiency begins to plateau and eventually begins to descend. Thus, for any particular task, we can talk about an optimal arousal level at which we have maximum behavioural efficiency.

Historically, measures of arousal/activation have been similar to the measures listed above in relation to the orienting reflex, except that they emphasize the tonic rather than the phasic aspects. Thus skin conductance level, heart rate and EEG measures have all been used as arousal indices. All reflect a defining characteristic of arousal in common usage - they are slowly changing state measures. They contrast with the phasic changes - rapid fluctuations in these same measures - associated with the orienting reflex.

Fractionation

In different situations these state measures simply do not covary well. Some of these different relationships have been well documented. For example, the effects of mental arithmetic differ from those of a simple vigilance task, in which the subject is waiting for a particular rare stimulus event to occur. From a baseline to a mental arithmetic condition, we find an increase in skin conductance level and an increase in heart rate. However, when we look at the change from baseline to a vigilance task, although there is an increase in skin conductance level, we find a decrease in heart rate. Essentially we have what is called "directional fractionation", i.e., the different measures of tonic arousal show different directions in their changes from a baseline condition. Lacey (1967) termed this "situational stereotypy", meaning that different situations produced different stereotyped tonic physiological patterns. He considered that vigilance involved preparation for stimulus intake, whereas mental arithmetic involved concentration on internal cognitive processing and required rejection of external stimuli. In the theoretical developments based on these sorts of directional fractionation of arousal measures, Lacey saw the cardiac changes as directly affecting central nervous system involvement in the task - a specific tonic cardiac response facilitated the appropriate CNS function. That is, Lacey proposed that the anticipatory heart rate decelerations seen in a vigilance task enhance cortical processing of environmental events. Increases in heart rate levels, associated with what he termed "stimulus rejection" tasks (such as mental arithmetic), reduce the efficiency of these same cortical areas, thus reducing the processing of external stimuli. These tonic changes may be considered to be broadly parallel to the phasic ECR1/ECR2 response components discussed above.

Such "fractionation" research brought to awareness specific problems with the concept of arousal. Arousal, rather than being a single or unitary construct, as used by the early workers in generating the inverted-U relation between behaviour and arousal, has been transmuted into a number of different "arousals". For example, we can now talk of different cardiac, electrodermal or electroencephalographic "arousals", which, although overlapping substantially, are not synonymous with each other - we observe fractionation of these "arousals" in different situations. Research has also shown significant non-overlap between clusters of autonomic, central and behavioural measures of arousal. Again we have a core, which is very important, but there are clear indications that these different forms of "arousal" are not equivalent.

These problems led to marked difficulties with handling arousal in the psychophysiological literature, and for some years it essentially fell into disrepute. Unfortunately this smacks of "throwing the baby out with the bath water", as there is still a useful core notion underlying these various aspects of arousal. I would argue that we must accept that the traditional unitary arousal concept was too simplistic, and that we should return to the study of such tonic indices. Rather than abandoning this area, we should attempt to develop and diversify our concepts of tonic physiological measures and integrate them with phasic indices of attentional processing in order to expand our explanatory power. From my perspective, the data presented by Lacey indicates that heart rate and skin conductance cannot both be indices of arousal, and we should examine the indices separately to conceptually accommodate the reliable fractionation data.

Recent work indicates that skin conductance level appears to function well as an arousal index. Something of this can be seen in a recent paper by Barry and Sokolov (1993). This attempted to bridge the theoretical gap between Sokolov's (1963) tonic OR concepts and the S process of Groves and Thompson (1970). The tonic OR may be considered as a state or arousal concept, encompassing an amplifying function that multiplies the output of the neuronal model/stimulus-comparator process to generate the phasic OR. Dual-process theory's S process is also a state concept that multiplies the output of the H process to generate phasic responses such as the OR. In this sense it is also analogous to the traditional notion of arousal/activation. Dual-process theory predicts an initial increase in sensitisation prior to the beginning of decrement with further stimulus repetition. Barry and Sokolov (1993) examined the tonic skin conductance level in a standard phasic OR type paradigm. We noted a sensitisation increase in level following the initial stimulus, which was then followed by a systematic slow decrement. In parallel, the phasic electrodermal response or GSR showed the expected rapid habituation (without initial sensitisation). We concluded that there was evidence supporting the identification of skin conductance level as an index of both the S process and the tonic OR, perhaps beginning a fusion of these two theories of phasic response habituation. In this and other studies, electrodermal levels of activity appear to behave in just the way that we would expect a traditional arousal or activation measure to vary.

On the other hand, heart rate does not appear to function well as an index of arousal. Rather, a decrease in heart rate level seems to be a good index of vigilance increase, i.e., we can take a decrease in prestimulus heart rate as a signal that the subject is increasing their vigilance, and vice-versa (e.g., Tremayne and Barry 1990).

This current approach allows us to look at electrodermal and cardiac levels as good measures of overlapping, but separable, concepts of arousal and vigilance (respectively) rather than as poor indices of the single construct of arousal. This is important for the promise it holds for future research - that by measuring electrodermal level and the level of cardiac activity we can separately index these two different state constructs, both important in on-going behaviour and cognitive activity.

We are also trying to broaden the range of indices associated with these two constructs. Work in progress with my colleagues at Westmead Hospital in Sydney has indicated that EEG activity in the beta band also functions as an index of arousal/activation in the waking state. We found increasing beta activity paralleling decreases in skin conductance level throughout a long-interstimulus interval auditory-oddball task. The skin conductance level data in this study replicated the sensitisation effect noted in Barry and Sokolov (1993). We are currently examining the role of EEG measures, particularly beta activity, in the amplification of the event-related potentials (ERPs) associated with the target stimuli. We intend comparing this with the analogous skin conductance level/GSR amplification.

TOWARDS AN INTEGRATED THEORY OF PHASIC AND TONIC ACTIVITY

Previous presentations of preliminary process theory have concentrated upon the fractionation of phasic measures associated with the OR. As outlined above, it is my thesis that we need to move beyond the fractionation of arousal/activation measures and replace the simplistic unitary arousal concept with at least the two constructs of activation and vigilance. Activation levels may be considered as state variables which amplify on-going activity in a general, undirected sense. In contrast, vigilance has a relatively narrow alerting function which may be directed by the organism in anticipation of events which require specific behavioural or cognitive activity.

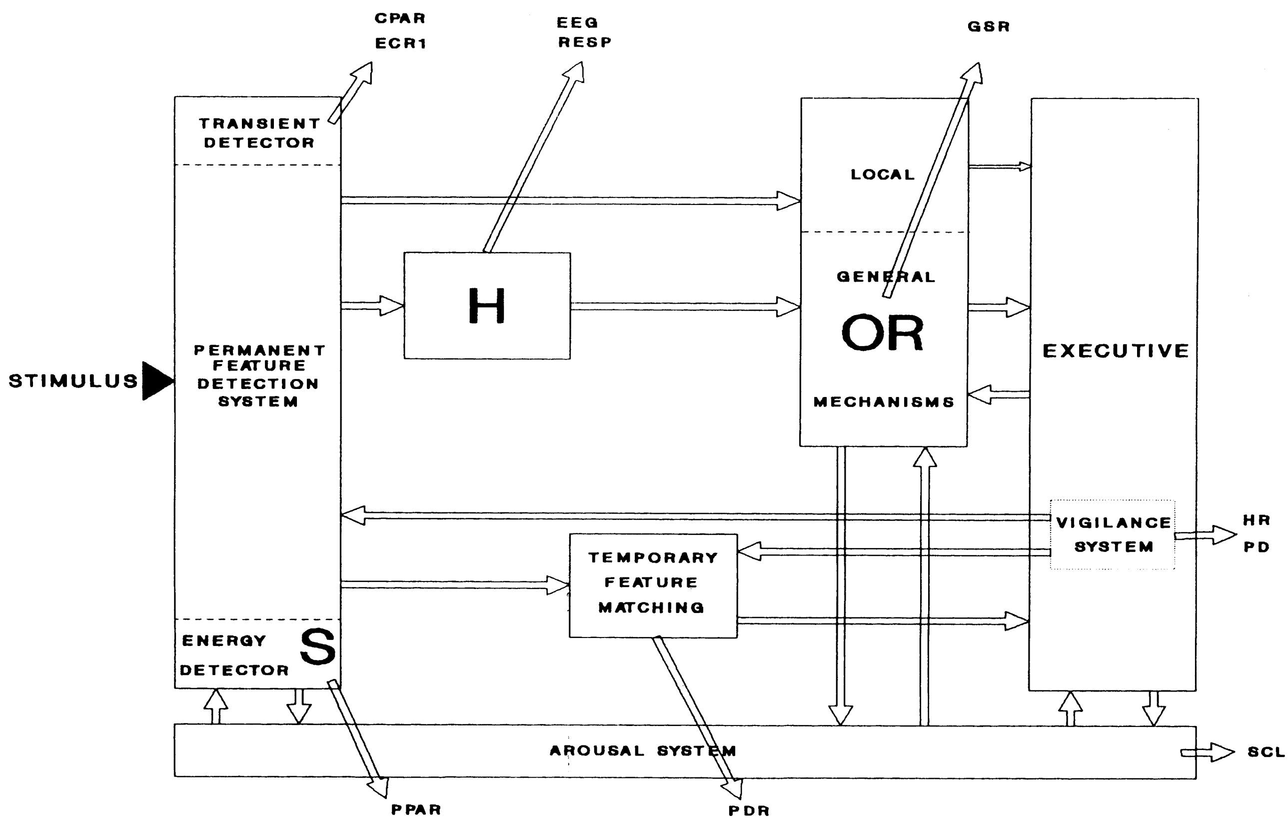

Fig. 5. A new representation of preliminary process theory, extending that of Fig. 4 and integrating state measures. H and S are the hypothetical processes of habituation and sensitization from dual-process theory. Additional physiological measures include: PD, pupil diameter; PDR, pupil dilation response; SCL, skin conductance level; HR, heart rate level.

Preliminary process theory plus state changes

Figure 5 outlines a schematic version of preliminary process theory modified to include both arousal and vigilance as state variables. In addition, some aspects of the presentation of the theory have been modified slightly in an effort to accommodate more central aspects of cognitive processing as might be reflected in ERPs.

The first stage in this version of the theory may be considered as the set of subsystems involved in processing the stimulus features - together forming a permanent feature-detection system. The primary subsystem here is that concerned with transient detection. The transient associated with the stimulus onset is now more clearly identified as the effective element of the stimulus occurrence which begins the sequential processing. This emphasis on the onset transient, and the transient-detection process, was first introduced in Barry (1983). This subsystem processing is reflected in the phasic responses of cephalic vasodilation (CPAR) and the initial cardiac deceleration (ECR1), as previously defined.

Another permanent part of this feature detection system is the subsystem concerned with evaluation of the stimulus energy. This includes the S process previously identified with the processing of stimulus magnitude and which innervates the phasic response of peripheral vasoconstriction (PPAR).

Arousal is considered as the crucial tonic element involved in the S process of dual-process theory, and stimulus intensity is considered to generate its effects through this general energizing aspect. Essentially, a stimulus event changes the state of the organism by contributing to the overall arousal/activation level in proportion to its intensity/magnitude/energy. The enhancement associated with this process early in a stimulus sequence is apparent as sensitisation, the S process which, under many conditions, enhances phasic responsivity early in a stimulus train. The interplay between arousal (indicated by electrodermal level, SCL) and the energy detection subsystem, as well as with other subsystems, is apparent in Fig. 5.

The outcomes of the preliminary processing carried out by the permanent feature detection system feed forward in a number of parallel streams. One stream passes to the OR generator *via* a stimulus novelty processing subsystem, labelled H in Fig. 5. This pathways subsystem results in response decrement, and is the major contributor to the habituation process (with S, the other process from dual-process theory). Another stream to the OR mechanisms bypasses the H subsystem, and is responsible for the slower-habituating elements in the "local" OR. This essentially reinstates Sokolov's concept of the local OR associated with modality-specific neural pathways. Thus, occipital alpha blocking was claimed by Sokolov (1963) to show slower habituation with visual stimuli because of its close association with the visual pathways involved. This local OR contrasts with the non-specific "general" OR largely focused upon in the literature, which is indexed in the current theory by the GSR.

Arousal/activation interacts with the OR mechanisms. An OR contributes to the arousal level, while the arousal level affects the OR magnitude through its amplifying function. This interaction is common to both dual-process theory and Sokolov's theory, and the compatibility of this aspect of the theories was pointed out in Barry and Sokolov (1993).

There are other feed-forward connections by which the OR impacts on the central executive, resulting in the involuntary switching of attention noted at the beginning of this paper. Both the local and general OR mechanisms contribute to this affect. The central executive can also affect the OR mechanisms. This is apparent in some examples of the enhancement of the OR associated with stimulus significance. As was noted when the concept of significance was introduced above, each of us will give an enhanced OR to our name in a list of words. This occurs when the general OR elicited by the word is enhanced - after attention switching occurs and the central executive feeds back to the OR mechanism.

Vigilance is considered as an important element of the executive processor, involving the more cortical aspects of stimulus processing. Its operation is indexed by both heart rate and pupil dilation (PD) levels. The latter index has been associated with vigilance for many years. The vigilance system can enhance the permanent feature detection system in a global fashion. This was discussed above in relation to the concept of an anticipatory increase in those aspects of stimulus processing involved in identification of a stimulus qua stimulus and preparation for subsequent emission of a prepared response. Such a chain of effects is most apparent in a speeded reaction-time task. In contrast, some aspects of stimulus significance are dependent upon identification of a target stimulus. In this case, the central executive calls into action a temporary feature-matching system. Its identification of a target stimulus matching the temporary feature set adds to the OR outcomes and is specifically apparent in the phasic pupillary dilation response. This last assertion is based upon research carried out with my colleague Manfred Velden in Osnabrück, Germany (Barry et al. 1987).

Integration with event related potentials

Integration of this schema with ERPs has been of interest for some time, but it has been difficult to articulate the existing version of the theory with ERP work. The major source of this difficulty lies in the paradigm gap between traditional autonomic OR work and ERP studies. The former uses long interstimulus intervals (ISIs) and relatively few stimuli in order to focus on trial-by-trial ORs and their habituation. In contrast, the latter typically uses very short ISIs, brief punctate stimuli, and large numbers of such stimuli. This large number is required by the averaging process used to derive the averaged ERP. By necessity, such paradigms almost guarantee that habituation processes will be totally obscured in the response averaging. Recent work with my colleagues at Westmead Hospital has indicated that it is possible to bridge this gap and to derive meaningful autonomic data from traditional ERP paradigms. Barry et al. (1992) were able to show that the response decrement commonly observed in the N100 component of the auditory evoked potential as a function of position in the stimulus train did not show the essentials of the habituation process. In the same paradigm, the GSR demonstrated unequivocally the required characteristics of habituation (Barry et al. 1993). Further studies have suggested that N100 shows the independence of stimulus intensity and novelty which characterizes the indices of the transient detector in Preliminary Process Theory. It is suggested here that such a tentative placement is worth further investigation.

Some current work in my laboratory is examining the effects of stimulus repetition on ERP decrement in a long-ISI paradigm. Using across-subject averaging rather than within-subject averaging, it appears possible to retain trial-by-trial information. There is evidence of a rapid habituation of the frontal P3a component, while N100 and a later posterior P3b fail to show such effects. My current hypothesis is that P3a may be a candidate for identification as an index of the novelty-encoding subsystem (H process), while P3b may reflect the temporary feature--matching process inherent in target identification. Current space limitations preclude a wider discussion of these hypotheses, including the large existing literature (which, unfortunately, is much reduced if the OR context is focused upon).

PHYSIOLOGICAL CORRELATES OF ATTENTIONAL PROCESSES

I would like to complete this outline of the development of preliminary process theory by providing a number of brief examples from recent research in which I have been involved. These have been chosen to indicate the range of interesting problems which can be investigated profitably in the context of the theory.

Pistol shooting

This project was carried out with Dr. Tremayne from the University of Western Sydney, and involved the examination of electrodermal and heart rate activity in elite pistol-shooters on the pistol range. We observed a systematic decrease in both measures prior to the pistol shot. Only HR discriminated the within-subject best/worst shots. HR deceleration prior to the best shots began some 15 s before the shot, and decreased steadily until the trigger was pulled. With the worst shots, the deceleration began some 2-3 s later and stopped some 3 s before the shot. From our perspective on the HR level as an inverse indicator of vigilance, we interpret this as indicating that the best shots were facilitated by a lengthy continuing vigilance process, involving a narrowing of attentional focus, which was maintained until the shot. The worst shots occurred when this narrowing of attentional focus was less systematic. The lack of differential electrodermal activity indicates that arousal level did not contribute to the performance difference. A second study of novice shooters indicated that the pre-shot cardiac deceleration developed in duration over a two-month training period.

Psychiatric patients - somatisation disorder

This project was carried out with colleagues in the Department of Psychiatry at Westmead Hospital in Sydney, under the direction of Dr. Evian Gordon. Somatisation disorder patients suffer a wide range of pain experiences which have no apparent organic cause. Some suffer conversion symptoms, in which a loss of function in an area is reported. We examined the N100 ERP component obtained from a standard auditory oddball paradigm. The response amplitudes of groups of somatisation disorder patients, with or without conversion symptoms, were compared with normal controls. Both patient groups exhibited larger N100s throughout the study, with those without conversion symptoms having the largest N100 amplitudes. From my perspective, this indicates a greater sensitivity to, or more extensive processing of, stimulus transients in these patient groups. Perhaps this increased sensitivity results in their processing stimuli associated with somatic discomfort as painful, leading to their frequent reports of non-organic painful symptoms. The role of conversion in this context is not readily apparent, but further directions for research are indicated.

Emotional impact in children of a challenging outdoor activity

This work is being carried out by Kerrie Wilde, one of my Ph.D. students. She uses an ambulatory monitoring device to record electrodermal activity and heart rate from children while they are engaged in an outdoor adventure Ropes Course. This is a challenging task which forms part of many modern outdoor physical education settings. She found that children generally tended to use two groupings of descriptors when asked to describe the elements of the course. Some of these descriptors were then used by a sample of children to rate the 6 elements of the course - in terms of fun/excitement and challenge/worry/hard. Subsequently she found that elements differing in fun/excitement were associated with different levels of skin conductance, but not HR. I interpret this in terms of SCL reflecting arousal differences associated with fun and excitement. In contrast, elements differing in challenge/worry/hard were associated with differences in heart rate, but not skin conductance. I interpret this in terms of an increased HR reflecting stimulus rejection while the children were on the elements which required most concentration on their balance etc., and which they found most worrying, challenging, and difficult. Kerrie Wilde is currently investigating changes in self-concept of children as a function of their physiological changes while undertaking the Ropes Course. This is in a theoretical context common within the physical education field, that overcoming "challenge" is considered to facilitate the development of a positive self-concept.

Tranquilizer effects on cognitive capacities

This project was carried out in Jan Kaiser's laboratory in the Department of Psychophysiology at the Jagiellonian University, Cracow, in a collaborative effort with other colleagues from Nijmegen in The Netherlands. Subjects were presented with a series of innocuous tones under two instructional conditions, counterbalanced in order between the subjects. These required the subject to silently count the tones for subsequent reporting to the experimenter, or indicated no stimulus-relevant task (indifferent condition). Each subject carried out the experiment under three drug conditions: placebo, buspirone, and diazepam, at 1 week intervals in a balanced order of drug presentation. Prestimulus HR levels were elevated with diazepam and depressed with buspirone. We interpret this as a differential drug effect on prestimulus vigilance: enhancement with buspirone and depression with diazepam. There were also differences in the deceleratory ECR1 (larger with diazepam, smaller with buspirone), which were in the opposite direction to the enhanced ECR1 which might have been expected to occur with the enhanced prestimulus vigilance associated with buspirone. However, the significance of these differences vanished when covaried with the prestimulus HR levels, indicating that the apparent differences in ECR1 arose only from the prestimulus HR levels. There were also significant drug effects in the acceleratory ECR2: enhancement with buspirone and reduction with diazepam, compared with placebo. These ECR2 effects were not mediated by the prestimulus vigilance effects, confirming the independence of the cognitive processes reflected in ECR1 and ECR2. These different cognitive effects of the two tranquilizers may be of some importance in choosing which to prescribe under particular circumstances.

CONCLUSION

This paper has presented an outline of an expanded theory of the psychophysiology of attentional processes, encompassing both phasic response indicators and separate tonic measures associated with arousal and vigilance. The beginning of an integration with central measures, particularly components of the ERP, was also presented. The theory was developed in the light of, and hence accommodates, the fractionation of response measures which has plagued the psychophysiological study of cognition. In accepting the realities which have negated earlier and simpler models of unitary responsiveness, preliminary process theory offers a new beginning, and provides a clear way forward. Some recent investigations in a range of areas of interest were briefly described, serving to illustrate the power of adopting a systematic approach which employs a range of physiological indicators.

A major advantage of the theory is its ability to generate novel experimental hypotheses which can be explicitly tested. In the testing process, new data may be described, which in turn will serve to enrich the arena of cognitive neuroscience. From the perspective of the theory, its success or failure in this predictive sense will serve to indicate its validity in the field.

REFERENCES

Barry R.J. (1977a) The effect of "significance" upon indices of Sokolov's orienting response: a new conceptualization to replace the OR. Physiol. Psychol. 5: 209-214.

Barry R.J. (1977b) Failure to find evidence of the unitary OR concept with indifferent low-intensity auditory stimuli. Physiol. Psychol. 5: 89-96.

Barry R.J. (1978) Physiological changes in a reaction-time task: further problems with Sokolov's dimension of stimulus "significance". Physiol. Psychol. 6: 438-444.

Barry R.J. (1979) A factor-analytic examination of the unitary OR concept. Biol. Psychol. 8: 168-181.

Barry R.J. (1982) Novelty and significance effects in the fractionation of phasic OR measures: a synthesis with traditional OR theory. Psychophysiol. 19: 28-35.

Barry R.J. (1983) Primary bradycardia and the evoked cardiac response in the OR context. Physiol. Psychol. 11: 135-140.

Barry R.J. (1984) Preliminary processes in OR elicitation. Acta Psychol. 55: 109-142.

Barry R.J. (1987a) Preliminary processes in orienting response elicitation. In: Advances in psychophysiology (Ed. P.K. Ackles, J.R. Jennings and M.G.H. Coles). Vol. 2. JAI Press, Greenwich, CT, p. 131-195.

Barry R.J. (1987b) Orienting and other responses to Preliminary Process Theory. In: Advances in psychophysiology (Ed. P.K. Ackles, J.R. Jennings and M.G.H. Coles). Vol. 2. JAI Press, Greenwich, CT., p. 285-339.

Barry R.J. (1988) Significance and components of the orienting response: effects of signal value versus vigilance. Internat. J. Psychophysiol. 6: 343-346.

Barry R.J. (1990) The orienting response: stimulus factors and response measures. Pavlovian J. Biol. Sci. 25: 93-103.

Barry R.J., Cocker, K.I., Anderson, J.W., Gordon, E., Rennie, C. (1992) Does the N100 evoked potential really habituate? Evidence from a paradigm appropriate to a clinical setting. Internat. J. Psychophysiol. 13: 9-16.

Barry R.J., Feldmann, S., Gordon, E., Cocker, K.I., Rennie, C. (1993) Elicitation and habituation of the electrodermal orienting response in a short interstimulus interval paradigm. Internat. J. Psychophysiol. 15: 247-253.

Barry R.J., James, A.L. (1981a) Fractionation of phasic responses in a dishabituation paradigm. Physiol. and Behav. 26: 69-75.

Barry R.J., James, A.L. (1981b) Fractionation of respiratory and vascular responses with simple visual stimulation. Physiol. Psychol. 9: 96-101.

Barry R.J., Sokolov, E.N. (1993) Habituation of phasic and tonic components of the orienting reflex. Internat. J. Psychophysiol. 15: 39-42.

Barry R.J., Velden, M., Wölk, C., Galvin, E. (1987) Pupillary dilation as a measure of the orienting response. Psychophysiol. 24: 578.

Groves P.M., Thompson, R.F. (1970) Habituation: a dual process theory. Psych. Rev. 77: 419-450.

Lacey J.I. (1967) Somatic response patterning and stress: some revisions of activation theory. In: Psychological stress: issues in research (Eds. M.H. Appley and R. Trumbull). Appleton-Century-Crofts, New York, p. 14-42.

Livanov M.N. (1977) Spatial organization of cerebral processes. Wiley, New York, 207 p.

Maltzman I. (1979) Orienting reflexes and classical conditioning in humans. In: The orienting reflex in humans (Eds. H.D. Kimmel, H. van Olst and J.F. Orlebeke). Erlbaum, Hillsdale, N.J., p. 323-351.

Sokolov E.N. (1963) Perception and the conditioned reflex. Pergammon, Oxford, 309 p.

Tremayne P., Barry, R.J. (1990) Repression of anxiety and its effects on psychophysiological responses to stimuli in competitive gymnasts. J. Sport Exercise Psychol. 12: 333-352.

Paper presented at the 2nd International Congress of the Polish Neuroscience Society; Session: Psychophysiology of cognitive functions