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SCHERER, Klaus R.

Abstract

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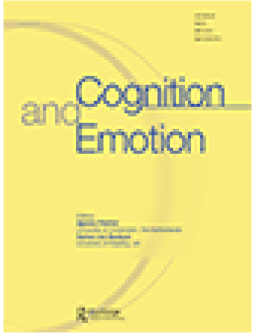

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Klaus R. Scherer

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Neuroscience Projections to Current Debates in Emotion Psychology

Klaus R. Scherer

Department of Psychology, University of Geneva, Switzerland

Possible contributions from different branches of the neurosciences to current debates in emotion psychology are discussed. The controversial issues covered in the paper include the nature of emotion, cognition-emotion interaction, the evaluative criteria used in emotion-antecedent appraisal processes, sequential vs. parallel processing in appraisal, differential patterning of discrete emotions, and possible entry points into the emotion system. Examples for neuroscience work that may be pertinent to these issues are drawn from neural network modelling, comparative studies of brain architecture and functional pathways in animals, experimental work in cognitive psychology, and case studies of brain-damaged patients in clinical neuropsychology.

INTRODUCTION

This paper is an attempt to illustrate how theoretical concepts and empirical results from the neurosciences[1] might contribute to some of the current debates in the psychology of emotion. I will outline some controversial

[1]In this paper the terms "neuroscience" and "brain research" are used somewhat summarily to refer to the many different subdisciplines and research branches in this interdisciplinary endeavour. The potential contributions considered here range from the work of neurobiologists working on the neural systems in the brains of animals over to clinical neuropsychologists working with brain-damaged patients to computer scientists involved in neural network modelling. Clearly, in addition to different subject populations, the methods used and the data obtained differ greatly between these approaches. Furthermore, there are major variations in research philosophy, some researchers being mostly interested in structural and functional brain organisation, others using brain manipulation as an experimental variable, and still others modelling brain activity. In the interest of economy of space these differences will not be discussed explicitly.

Requests for reprints should be sent to Klaus R. Scherer, Department of Psychology, University of Geneva, 9 route de Drize, CH-1227 Carouge, Geneva, Switzerland.

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questions in emotion psychology and suggest potential evidence from the neurosciences that might help to advance our understanding of the processes likely to be involved. In order to evaluate the significance of such contributions, we need to sharpen the conceptual issues underlying the current controversies in emotion psychology. Much of the paper aims at such conceptual clarification (admittedly with some bias towards my own theoretical views).

Given this goal, this paper does *not* exhaustively review pertinent neuroscience studies nor does it cite all the work relevant to the issues raised. The scope of the following discussion is more limited. It is motivated by the desire to provoke a discussion of the possibility to advance theoretical insight and experimental test by importing expertise from a newly constituted interdisciplinary approach that might have privileged access to some aspects of the phenomenon. In consequence, the paper consists mainly of questions rather than assertions.

The approach suggested here may be suspect to those psychologists who are worried by the dangers of reductionism. Yet, although the study of the neural substratum of psychological processes does not necessarily resolve functional questions, one can argue that more detailed knowledge of the *biological constraints*, concerning both structures and mechanisms, can help to select between different theoretical alternatives and to direct psychological research toward areas or topics that are crucial for our understanding of the phenomenon of emotion. Eimas and Galaburda (1989), in introducing a special journal issue on the neurobiology of cognition, have cited F.O. Schmitt (1978, p. 1): "... theories of higher brain function (learning, memory, perception, self-awareness, consciousness) ... in general lack cogency with respect to established anatomical and physiological facts and are without biophysical and biochemical plausibility." One could easily add "emotion" to the list enumerated by Schmitt. Eimas and Galaburda discuss the difficulty involved in moving from one level of explanation to another and the complexities involved in the mind-body debate. They conclude that it is an empirical question to determine to what extent it is possible to explain observations made under one metaphor, e.g. psychologically defined cognitive functions, in terms of observations derived from the use of another metaphor, neurobiological models of the brain. I believe the same to be true for emotion: We should examine empirically to what extent the use of neuroscience metaphors can be usefully employed to further our understanding of the psychology of emotion and vice versa.

Furthermore, many neuropsychological studies of emotion-related issues deal with *pathology* thus allowing for natural experiments that would be unthinkable in the context of standard psychological field studies or laboratory experiments. For example, although the study of brain-damaged patients certainly carries its share of methodological and conceptual difficulties, it might provide insight, through case studies, into normal structure and functioning. Needless to say, the study of pathology and malfunctioning has been one of the royal roads for the understanding of normal functioning in most of the life sciences (as well as in engineering).

Also, *comparative research*, using animal experimentation, although increasingly under attack from animal rights groups, is still far more ethically acceptable to most than experiments involving the induction of strong emotions in humans. There can be little doubt that the ethical and practical difficulties of producing different emotions in human subjects is one of the most serious drawbacks for advances in experimental emotion research (see Wallbott & Scherer, 1986; Scherer & Wallbott, submitted). There is no question that it is difficult to generalise from the animal model to the human case. However, from a psychobiological point of view a comparative approach, highlighting the phylogenetic continuity of many basic behavioural mechanisms, can yield very important insights (at least with respect to some rudimentary modes of functioning).

I will discuss six controversial issues which I believe to be theoretically important and which are currently debated in the field: (1) the nature of emotion; (2) cognition-emotion interaction; (3) the nature of the appraisal process; (4) sequential vs. parallel processing; (5) differential patterning; and (6) entry points and intersystem feedback. In each case, I will outline my own view on the issue and describe opposing views. Again, the emphasis is not on comprehensiveness nor on doing justice to the different theoretical models that have been proposed. Rather, the interest is in trying to evaluate how and to what extent neuroscience approaches might help to clarify the issue or to suggest a possible experimental paradigm. The task, then, is to generate interest in closer collaboration between researchers focusing on the psychology of emotion, mostly working on emotion efferents such as expression, autonomic reaction, and subjective experience, and neuroscientists interested in the central mechanisms and functional pathways involved in the elicitation and control of affective behaviour.

1. THE NATURE OF EMOTION

A fundamental condition for fruitful debate and cumulative research is agreement on the nature of the phenomenon. Whereas laymen seem to share a common concept of the emotions, scientists have a very difficult time to agree on the definition of emotion, although there is some consensus that emotions are constituted by different aspects or components (Kleinginna & Kleinginna, 1981). Most theorists endorse the classic "reaction triad" of physiological arousal, expressive behaviour, and subjective feeling, others add motivational state/action tendency and/or cognitive processing. However, there is next to no agreement on (a) how these components are organised during emotional arousal (as distinct from the functioning of the respective organismic systems during nonemotional states), (b) when and how an emotion begins and when it ends, and (c) how many different emotions can be distinguished.

Defining Emotion Episodes

In the context of a *component process theory* (Scherer, 1983, 1984a,b, 1986) I have suggested to define emotion as an episode of temporary synchronisation of all major subsystems of organismic functioning represented by five components (cognition, physiological regulation, motivation, motor expression, and monitoring/feeling) in response to the evaluation of an external or internal stimulus event as relevant to central concerns of the organism.

It is claimed that although the different subsystems or components operate relatively independently of each other during nonemotional states, dealing with their respective function in overall behavioural regulation, they are recruited to work in unison during emergency situations, the emotion episodes. These require the mobilisation of substantial organismic resources in order to allow adaptation or active responses to an important event or change of internal state. The emotion episode is seen to begin with the onset of synchronisation following a particular stimulus evaluation pattern and to end with the return to independent functioning of the subsystems (although systems may differ in responsivity and processing speed). As stimulus evaluation is expected to affect each subsystem directly and because all systems are seen to be highly interrelated during the emotion episode, regulation is complex and involves multiple feedback and feedforward processes. For this reason, it is assumed that there is a large number of highly differentiated emotional states (of which the current emotion labels capture only clusters or central tendencies of regularly recurring states).

Needless to say, the definition suggested earlier is only one out of many. There are as many alternative definitions of emotion as there are theorists. Emotions are variously defined as changes in arousal, as innate neural programmes, as responses to discrepancy, as social constructions, as cognitive schemata or prototypes, as action tendencies, as interrupt mechanisms, as epiphenomena, etc. To just list the various definitions or cite the respective theorists would take a paper of its own. Such a paper would still be incomplete because only very few theorists have published comprehensive accounts of their emotion definition. It would be useful to ask each emotion theorist to state, minimally, the position of the respective theory on the following questions:

- How are emotional states different from nonemotional states?
- How do emotion episodes start and when and how do they end?
- How are emotions differentiated and how many types are there?

Clear responses to these questions would help to sharpen the conceptual distinction between different definitions and allow the elaboration of criteria as to which definitions are more or less appropriate to specify the process or mechanism that is meaningfully distinguished as emotion from other fundamental classes of states, mechanisms, or behaviours in the social, behavioural, and life sciences.

In line with the approach taken in this paper, we will ask whether neuroscience approaches can help to choose between competing emotion definitions or to bring about a rapprochement by helping to develop criteria for necessary conditions. It is often argued that definitions are arbitrary and not subject to being disproven. From a strict *theory of science* view, this is probably true. Different definitions of a phenomenon entail different criteria for establishing its presence or determining its nature. As these criteria may not always overlap for different definitions, one can argue that evidence cannot be used to judge the well-foundedness of a definition.

However, from a *practice of science* point of view this is quite debatable. Definitions are important signposts for research and for scientific discussion. In the social and behavioural sciences they should not, unless clearly warranted, stray too far from phenomenological evidence and common language usage. But they should also remain closely tied to evidence about the nature of the organism and its functioning. In the latter sense, neuroscience evidence could be helpful to settle some aspects of definitional disagreement. At least for practical purposes, i.e. decisions about research and publication priorities, it is useful to ascertain that the definition proposed has some chance to correspond to an actual phenomenon and to generate theories (including hypotheses and their operationalisations) that have a chance to be tested empirically. For example, if neuroscience work would provide evidence for phylogenetically continuous, biological emotion mechanisms, it would be difficult to insist on a definition of emotion as an *exclusively* socially constituted cognitive schema requiring language for its instantiation (Averill, 1980; Greenwood, 1991; Harré, 1986; see Scherer, 1991). Similarly, if it could be shown that the respective biological mechanism can be triggered in a way that produces highly stereotyped response patterning, a definition of emotion as an innate neural programme (Ekman, 1972; Izard, 1971, 1977; Tomkins, 1962, 1963, 1984) would seem to be strongly encouraged. Examples for the rudiments of such programmes might be the spontaneous occurrences of patterns of facial expressions observed at the onset of epileptic seizures, and unmotivated eruptions of anger, crying or laughter, as observed in some cases of brain damage (Feyereisen, 1989; Poeck, 1969; Valenstein & Heilman, 1979). In this sense, evidence about brain organisation and evolution may well be useful—on a pragmatic level—to evaluate the relative usefulness of a definition for hypothesis generation. Some specific examples will illustrate this point.

Differences between Emotional and Nonemotional States

A major tenet of the definition proposed in the component process model is the notion that *all* organismic subsystems are involved in emotion—in contrast to nonemotional states where each subsystem is focused on its particular function. Neuroscience evidence is highly relevant to this claim. As all of the subsystems involved in the synchronisation during an emotional episode are controlled by the central nervous system (CNS), a synchronisation of the activity of the different parts of the CNS that subserve the different component processes constitutes the core of the assumed mechanism. Ideally, then, one might want to begin the search for multisystemic synchronisation at the level of the CNS, attempting to trace simultaneous activation spread across several different centres and pathways, including, in particular, the control sites for cognitive, motor, and autonomic activity.

It is instructive to use recent theorising in the area of memory retrieval as an analogy. Damasio (1989) has suggested a theoretical account for the neural substrate of memory recall that is based on a notion of time-locked multiregional retroactivation. It is suggested that rather than being stored in an integrated fashion in a single brain location, different components of memory contents are distributed in fragmented form over many different brain sites. Retrieval of the memory content is seen to be achieved through a synchronisation of the activity of the multiple sites involved. According to Damasio (1989, p. 56), the fragmentary records that are reconstituted through time-locked retroactivation are contained in multiple sensory and motor regions. Due to the involvement of motor regions, somatic states or somatic involvement in stimulus processing (as would be the case in emotion memory) are stored and recalled in a similar fashion. In consequence, a specific memory content could be characterised by the unique spatio-temporal patterning of the brain activity involved in storage and retrieval (including aspects of both sensory input and motor output).[2] Similarly, within the framework of the definition suggested above, one

[2] I am most grateful to an anonymous reviewer for suggesting this analogy with recent neuropsychological memory models.

could conceptualise different *emotions* as unique sets of spatio-temporal patterning of brain activity, including the specific patterns of appraisal that elicited and differentiated the feeling state and the peripheral somatic and autonomic reactions.

Such unique spatio-temporal CNS activation patterns would then be stored in memory as distinctive emotion experiences whereas the nonintegrated, nonsynchronised activation patterns during nonemotional states would not normally be expected to leave any traces. This has interesting implications for the recall of emotional experiences from memory, for example via imagery. If indeed retrieval of an emotional memory were to be achieved via reproduction of the original, unique spatio-temporal synchronisation pattern (based on time-locked retroactivation of fragmentary multiregion patterns), it would seem highly plausible that a similar, albeit much weaker, emotional state is reproduced and experienced at the moment of the retrieval of the emotional situation from memory. In consequence, the specific characteristics of emotion episodes might well be elucidated by studying the neuropsychology of emotion memories.

Another neuroscience approach to determine differences between emotional and nonemotional states might consist of the study of dissociations between different components as they are often found in pathology. Clinical neuropsychological observation has yielded quite a few reports of patients that show rather dramatic bouts of crying and weeping or hysterical laughter (involving both the expressive motor system and the autonomic nervous system: ANS) without any corresponding cognitive evaluation or subjective feeling component (Churchland, 1986, p. 222; Poeck, 1969). According to the component process definition (and consistent with some patients' own opinion, see Churchland, 1986, pp. 222–223), these patients are not experiencing an emotion during such unmotivated expressive outbursts (except, possibly, for a complex blend of anger, shame, and fear that might result from feeling powerless in controlling such events). Conversely, there are observations of lack of expression even though a patient is experiencing strong feelings (Feyereisen, 1989, p. 278). Such patients would be most interesting sources of information for the study of the interrelationships between emotion components and the constitutive role of synchronisation of different components.

If the claim that the major definitional criterion for an emotional state is the synchronisation of several subsystems, there should be no special structures, at least on a low level of neural integration, that *exclusively* process emotional information and behaviour (see Feyereisen, 1989, p. 272; LeDoux, 1989, pp. 267–268).

The controversy between Gray and Panksepp in the special issue of *Cognition and Emotion* on the development of relationships between emotion and cognition (Vol. 4, Issue 3, 1990) illustrates the stimulating effect of arguing this issue on the basis of concrete neurophysiological systems. Although Gray (1990), based on his theory of anxiety as well as pertinent evidence, claims that the same brain systems may mediate both emotion and cognition, Panksepp (1990) strongly asserts the need to keep focused on the primitive "primary emotional operating systems" which he links to specific types of neural circuits in the brain. Panksepp's criticism of Gray's central assumption that reward, punishment, and nonreward constitute the major organisers of the combined systems, i.e. that reinforcement is probably a consequence of emotional processing rather than an input, is well taken (an objection that also applies to Rolls, 1990). However, it is equally difficult to accept Panksepp's position that only the additional random access memory in the human neocortex makes for partial interaction between cognitive and emotional processes, with the latter being totally precognitive and operating via intrinsic biological rules, at least for the primary emotions. The notion that man preserves some quasi-autonomous primitive emotion systems that are only peripherally affected by higher functions added on in the course of evolution, does not seem to correspond to the way in which phylogenetically older and more recent systems typically interact. In any case, both parties in the debate adduce evidence and suggest further research which could help to advance the debate of the issue.

As is implied by the synchronisation notion, I am not convinced by the available evidence or the theoretical claims for emotion-specific neural circuits or systems. It is interesting to quote a neurochemical approach in this context. Based on recent work on neuropeptides, Pert, Hill, and Zipser (1988, p. 313) doubt the existence of emotion-specific neural circuits: ". . . a function as complex as the modulation of emotion, requiring the integration and coordination of the perceptions of both the internal and external milieu, perhaps requires much of the brain and body and includes regions which overlap with many other systems."

Assuming that the systems are indeed interdependent (see also Smith, 1991; Wexler, 1986), we should not be able to find neural damage that affects emotion only with *no* side-effects on cognition (i.e. perception, memory, attention, or reasoning), motivation, or other organismic subsystems. On the other hand, we should find pathologies where the presence of neural impairment in one or more *non*emotional subsystems leads to a major change of emotionality. A classic example is flat affect or emotional blunting which is often observed in patients with lesions in the frontal lobe areas. In these cases, cognitive deficits often seem to go hand in hand with emotional blunting. Luria, Pribram, and Homskaya (1964) have linked frontal lobe damage induced failure of verbal regulation and fluency to flat expression and pseudo-depression. Valenstein and Heilman (1979, pp. 421–430) provide a detailed review of the way in which impairment of the links between end-organs and cortical centres will affect emotionality through interference with appropriate cognitive processing. Depending on the site of the lesion with respect to the connections between cortical and limbic areas (producing disinhibition) different emotional disturbances can develop. Inappropriate affect because of frontal injury can consist of abnormally heightened irritability/anger, silliness, or defects in phasic arousal depending on the site of the lesion (see also Beaumont, 1983, p. 62). Contrary to true emotional lability, in some cases of subcortical defects inappropriate affect displays may occur even though the patients report normal feeling states (Valenstein & Heilman, 1979, p. 430). Some of the most compelling evidence for the important role of the frontal lobes in affective regulation has been reported by Robinson, Kubos, Starr, Rao, and Price (1984). These researchers found a strong correlation between the proximity of a lesion to the frontal pole within the left hemisphere and the severity of depressive symptomatology (see also the discussion of this issue in Davidson & Tomarken, 1989).

The Beginning and Ending of Emotion Episodes

Although the elicitation of an emotion, which often occurs quite abruptly, is rarely discussed, the question of emotion duration and the ending of emotional states has given rise to some controversy.

Researchers who have studied first-hand emotion accounts via verbal report find that respondents often claim that some emotions (especially sadness) last not only for hours but even days or weeks (Frijda, Mesquita, Sonnemans, & van Goozen, 1991; Scherer, Wallbott, & Summerfield, 1986; Scherer & Wallbott, submitted). On the other hand, Ekman (1992) in trying to distinguish discrete emotions from moods proposes to limit the duration of real emotions to a few minutes, presumably considering the disappearance of the distinctive universal expression as the end of the emotional state.

Let us assume we had access to neuroscience techniques which can demonstrate the participation of several central subsystems in emotion arousal, allowing to monitor the temporal engagement and disengagement or the degree of synchronisation of these processes with high temporal resolution. With appropriate multivariate time series procedures, one could then attempt to specify parameters and criteria to determine beginnings and endings of emotions and to trace the difference between emotional and nonemotional states, as suggested by the synchronisation feature of the component process definition. For example, monitoring of continuous correlates of central processes (e.g. through the electroencephalogram: EEG) could be used to obtain evidence for or against the existence of relatively sudden onsets and offsets of very complex patterns (going beyond simple orientation or defence responses in stimulus processing). This type of response pattern would have to be predicted by the postulate of innate neural programmes in discrete emotion theories because the notion of a programme implies that the corresponding processes are switched on and off in a relatively bounded and tightly organised fashion. Conversely, if the notion of a gradual synchronisation and cumulative state changes were to be correct we should find much fuzzier patterns of change.

Number and Differentiation of Emotions

The definition of emotion largely determines one's view of how many different emotions there are and how they are differentiated. But even within the same family of emotion theories, e.g. discrete emotion theories, there are disagreements about the number and types of basic emotions and the criteria used to determine their status. For example, although Ekman (1992) considers the existence of a universal facial expression pattern to be the prerequisite for the status of basic emotion, Izard (1971, 1977) proposes the adaptive role of specific discrete emotions systems and their emergence in ontogenesis as pertinent criteria. Dimension theorists (e.g. Russell, 1980) seem more concerned with basic differentiating dimensions rather than individual emotions, as the dimensional space will accommodate any number of verbal labels.

Component process theory suggests the existence of as many different emotions as there are characteristic patterns of situation and event evaluation (with corresponding effects on the changes and the synchronisation of the various subsystems), suggesting that there are a certain number of *modal emotions* elicited by frequently recurring, prototypical evaluation outcomes. It is argued that because of their frequency and because of the need to be able to refer to them in communication, these prototypical or modal states are labelled with a concise term in most languages.

Can the neurosciences help to settle the issue concerning the number and differentiation of emotions? One important task would be to establish whether different emotions are based on different or the same substrate system (Feyereisen, 1989). If neuroscientists were to agree that there are only a very small number of highly specific neural circuits for different emotions (as claimed by Panksepp, 1982), the hypothesis of a limited number of discrete, innate systems would be strengthened. If, on the other hand, the evidence would point into the direction of fuzzy neural networks with variable patterns of activation, one might consider component process theory a more appropriate conceptualisation.

With respect to pathology, one could study whether emotion disturbances are unitary or fragmentary. For example, do different lesions affect emotionality generally or are some emotions differentially affected because only their specific neural circuit or substrate is destroyed or damaged. If the latter holds, and if the structures or circuits involved can be reliably identified, we should be able to find patients with only some emotions affected, the remainder functioning perfectly normally. A very germane area of study is the use of positron-emission tomography (PET) scans to identify the structures involved in normal anxiety and in panic disorders (Reiman, Fusselman, Fox, & Raichle, 1989). A recent study even reports correlations between the activation of different cerebral areas (as measured by PET scans) and different types of anxiety and hostility (Gottschalk et al., 1991). However, one may need to exert great caution to exclude the possibility of artefacts, such as anxiety-induced hyperventilation on cerebral bloodflow (see Mountz et al., 1989). Another possible source of artefacts is the effect of emotion-induced muscle movements. Drevets, Videen, MacLeod, Haller, and Raichle (1992) have shown that teeth clenching produces increased blood flow near the temporal poles in a region close to that implicated by Reiman et al. (1989). Using sophisticated multiple assessment procedures, Drevets et al. localise this blood flow change to an extracranial area that presumably reflects the activity of the temporalis and masseter muscles. A series of controls are suggested to distinguish changes in muscle blood flow from potential flow changes in the paralimbic temporo-polar cortex.

2. COGNITION-EMOTION INTERACTION

The relationship between cognition and emotion is one of the most vexing problems—and one of the most persistent sources of controversy—in the psychology of emotion today. If one looks closely at the issues being debated, one notices that the dissension invariably turns around a conceptual issue: The *definition of cognition*. This has been the case in the Zajonc-Lazarus controversy which Leventhal and Scherer (1987) have analysed with respect to the semantic issues involved (e.g. the role of meaning; the difference between perception and cognition). The nature of cognition has again been at issue in the controversy on Bischof's emotion model which defines cognition as any process which reflects different states of the world (Bischof, 1989; Dörner, 1989; Scherer, 1989). Because the neurosciences are often considered as part of cognitive science we can look for help to find a set of discriminanda to get out of the morass of fuzzy distinctions.

The Definition of Cognition

Rather than attempting to agree on a definition of cognition it might be better to argue concretely in terms of *stimulus coding* or *stimulus transformation* and to study the structures, levels, and mechanisms involved.

Neuroscientists should be able to contribute by identifying the structures and pathways as well as the recoding or transformation processes that take place in emotion-antecedent cognition. The neuropsychologist LeDoux (1987) has in fact attempted to arbitrate the Zajonc-Lazarus debate in these terms. He argues that: (1) Lazarus may be right that there is always some stimulus transformation in emotion-antecedent information processing but that this may not be cognition in the sense of conscious or cortical processing; (2) Zajonc is probably wrong in suggesting that no transformation is necessary, but is probably right in that processing affectively relevant stimuli does not necessarily involve cognition in the sense of high-level processing.

LeDoux asserts that each organism must perform some computation of stimulus significance (a prerequisite for learning) in order to assign emotional valence to stimuli. With respect to the labelling of this process, he succinctly argues (1989, p. 271): "The process involved in stimulus evaluation could, if one chose, be called cognitive processes. The meaning of the stimulus is not given in physical characteristics of the stimulus but instead is determined by computations performed by the brain. As computation is the benchmark of the cognitive, the computation of affective significance could be considered a cognitive process." He goes on to point out that because the mechanism that performs the computation of the affective significance of stimuli is the precursor to conscious emotional experience, it operates outside of conscious awareness.

For the purpose of discussing cognition-emotion interaction I suggest to define cognition in the widest sense of stimulus recoding or computation of significance. With Leventhal, I have argued for the need to define more precisely what kind of cognitive operation is implied and on what level of the CNS (and of recoding or storage complexity) it occurs. Based on Leventhal's earlier distinction between sensori-motor, schematic, and conceptual processing in emotion-related cognitions, we have proposed a preliminary classification of emotion-related information processing with respect to these three levels (Leventhal & Scherer, 1987).

Cognition as Part of Emotion

Although few theorists would deny that in many cases there is some cognitive processing at the onset of an emotional state, the debate turns around the question of whether cognitive processing is part and parcel of an emotion episode. Some theorists consider cognitive appraisal as the eliciting and differentiating agent but see it as a precursor or antecedent of emotion, not as part of or component of it. Others seem to deny a major role of cognition, but it is not quite clear what mechanism for emotion elicitation, differentiation, and regulation they postulate instead. For example, Ekman (1984), Izard (1971, 1977), and Tomkins (1962, 1963, 1984) postulate that innate neural motor programmes are triggered by characteristic eliciting situations. Mandler (1984) sees interruption and inconsistency as the eliciting factor, with cognitive interpretation and attribution playing a secondary role.

As is implied in the synchronisation definition presented earlier, I consider cognitive processes (in the wider sense) to form a *part of the emotion process*. It is one of the major components that gets synchronised with other organismic systems during the emotion episode. In fact, it is considered generally to play the leading role in the synchronisation by triggering the onset of the process and by determining its duration and course (especially the differentiation of emotional states through the results of sequential appraisal processes; see below). Obviously, this is not a one-way process. Due to feedback and feedforward interconnections between the systems, cognition will itself be affected by changes in other subsystems (as has been pointed out and illustrated early on in the history of emotion psychology, cf. Rapaport, 1971; see also Blaney, 1986, for a recent review on memory).

Cognition is also involved in another emotion component—subjective feeling. Component process theory considers subjective feeling as part of a monitor system that reflects the actual state of all other organismic systems. Emotional feeling acquires its powerful impact in part because of the synchronised changes across the total organism that are being monitored during the emotion episode. Part of this monitored information is available to consciousness and can be verbalised. Other parts are not readily available although they might be accessible to awareness with proper attention deployment. Although we might not want to talk about "unconscious feelings", we again face the question of what type of information processing is occurring in the monitoring of the changing states of our different organismic subsystems.

It is instructive to compare the synchronisation idea with a speculative account from neuropsychology concerning the basis of affective feeling states (LeDoux, 1989, p. 283): "By integrating stimulus representations, affective representations, and stimulus-affect representations with a representation of self (which remains as mysterious a concept as ever), an affectively charged experience, a feeling about the significance of the stimulus, might result." If one were to add the different peripheral systems involved in emotional arousal, we would be very close the notion of a unique spatio-temporal activation pattern as constituted by the synchronisation of different systems.

Monitoring of Cognitive Processes

Much of the argument presented above hinges on the notion of the synchronisation of many different systems. How can this idea be tested empirically? Recent methodological advances in brain research have the potential to provide evidence on how many subsystems are involved in emotional arousal. As mentioned before, all component processes are controlled by central structures and a complete assessment of central neural activity should therefore allow to determine the relative contribution of different systems. If the control sites differ for different types of functions an analysis of which sites are simultaneously activated should allow to draw reasonable inferences about the synchronisation of different subsystems during emotional states.

The mapping of different brain functions has been one of the major aims of neurophysiological research and the literature abounds with studies demonstrating in ever more detail both the localisation and, due to extraordinary advances in staining techniques, the pathways for a large variety of cognitive and motor functions. Of course, invasive studies in animals or case studies from human brain surgery do not allow to go beyond the demonstration that a particular CNS structure is vital for the unimpaired performance of a particular function. To demonstrate the simultaneous, normal activity of different brain centres one needs to be able to monitor the neural activation in a normally functioning brain, which requires the use of noninvasive techniques. Both classic electroencephalographic (EEG) recording and modern imaging techniques offer the opportunity for such monitoring of ongoing distributed brain activity.

The use of EEG techniques to study emotion is well established (Ray, 1990). Much of the work has been directed toward the study of hemispheric dominance, in particular testing the hypothesis that the right hemisphere is the predominant site for emotional processing. Although the literature in this area keeps growing, it might be too early to draw definite conclusions because the effect sizes of the results are small and replications are rare (reviews in Davidson, 1984; Gainotti, 1989; Heilman & Satz, 1983; LeDoux, 1984; Tucker & Frederick, 1989; see also the contributions by Gainotti, Caltagirone, & Zoccolotti and Làdavas, Cimatti, Del Pesce, & Tuozzi, this issue).

A research strategy aiming at demonstrating the superiority of one hemisphere in a relatively global fashion does not respond to the need of assessing the simultaneous activity of several centres. However, as Feyereisen (1989) has pointed out, neuropsychology allows a much finer analysis than that offered by the crude dichotomy opposing right vs. left hemispheres (or affect vs. cognition). Recent EEG work has demonstrated that finer resolution can be attained. Davidson and his colleagues have embarked on a research programme designed to test the hypothesis that positive emotions entailing an approach component are accompanied by greater left anterior (e.g. frontal and anterior temporal regions) activation, whereas negative emotions involving an avoidance or withdrawal tendency will be associated with greater relative right-sided anterior activation (Davidson, 1984; Davidson, Ekman, Saron, Senulis, & Friesen, 1990). In a recent study, Ekman, Davidson, and Friesen (1990) found that the Duchenne (enjoyment) smile (see Ekman, 1989) was associated with more left-sided anterior temporal and parietal activation as compared to other smiles. Although the greater anterior temporal activation was predicted, the parietal involvement was not. The authors surmise that this might be due to more verbal thinking accompanying the Duchenne smiles compared to other smiles (because verbal cognitive activity reliably increases left parietal activation; Ekman et al., 1990, p. 351). If these interpretations are correct we would seem to have preliminary evidence for synchronisation of at least four of the components mentioned earlier: the positive feeling state; the approach action tendency; a clearly defined motor expression; and some form of cognitive activity. Although this is still a far cry from determining the unique spatio-temporal patterning serving as signatures for very specific emotional states, it certainly points out the direction for future research.

If one could define reliable central indicators for the processing in the different component subsystems, it might be possible to be more concrete about the nature of the interaction between cognitive processes (in the wider sense) and the emotion components commonly accepted (such as expression, physiological change, and feeling). One of the major tasks in the effort to fine-tune our ability for noninvasive monitoring of central processes is to understand better the content of what is being processed. One approach consists of measuring event-related or evoked response potentials (ERP) in an attempt to determine the content of the underlying processing by correlating ERP patterns with known events or stimuli to which the person has been exposed (Coles, Gratton, & Fabiani, 1990; Hillyard & Kutas, 1983).

It is not excluded that progress in this area will allow greater differentiation of cognitive operations or motivational states than is the case today. If that were to be the case, one might be able, using both central indicators and peripheral parameters for the autonomic and somatic nervous systems, to settle whether cognitive processing is an antecedent event, occurring in a burst before the onset of emotional arousal or whether there is, as I suggest, a steady process of integration and synchronisation between the different components, including the cognitive one. Such an approach might help to elucidate the process character, the unfolding, of emotion in relation to the constant change in cognitive evaluation of the situation the organism finds itself in.

An interesting example for the potential use of ERP in investigating the synchronisation of different components in emotional states is provided by the work of Simons, MacMillan, and Ireland (1982). These investigators showed that the inability to experience pleasure in subjects reporting physical anhedonia seems linked to a lack of concordance in different response systems (peripheral measures, EEG, and verbal report).

Recent progress in scanning and imaging techniques has been stunning. The various techniques include computerised axial tomography (CT scanning), cerebral blood flow (CBF) measurement, positron-emission tomography (PET scanning), nuclear magnetic resonance (NMR) imaging (see Churchland, 1986, pp. 217–221 for a nontechnical overview). Spatial and temporal resolution of these imaging methods, especially the PET scanners, are constantly improving and there are now a number of convincing illustrations showing that not only the respective sites for major functions such as visual vs. auditory perception, episodic vs. biographical memory, cognitive or motor planning can be mapped but also the response to different stimulus features (e.g. tone sequences vs. tonal features) and different perception strategies (e.g. use of visual imagery). It is to be hoped that these techniques will become available for more systematic research on emotional processes by further reductions in the invasiveness and the cost of these procedures. One of the major limitations of the current imaging techniques is their relatively low resolution in the time domain which does not allow to study rapidly occurring neural processes.

In principle, assuming that all the messy practical problems can be solved by future technological development, the question of the simultaneous, synchronised activation of different subsystems could be beautifully studied with high-resolution PET scans. If typical activation patterns for the individual systems under their normal functioning can be established, emotion induction should produce synchronised changes in the metabolic activity of the different brain regions associated with individual functions. If appropriate temporal resolution can be attained, such studies might even allow to assess differential response latency, lag times, or general processing speeds of the different systems.

3. THE NATURE OF THE APPRAISAL PROCESS

Following pioneering work by Arnold (1960) and Lazarus (1966), a number of theorists have independently developed models of emotion-antecedent appraisal, all attempting to predict emotion elicitation and differentiation on the basis of a limited number of cognitive dimensions or criteria (Frijda, 1986, 1987; Johnson-Laird, & Oatley, 1989; Ortony, Clore, & Collins, 1988; Roseman, 1984, 1991; Roseman, Spindel, & Jose, 1990; Smith & Ellsworth, 1985, 1987; Scherer, 1981, 1983, 1984a,b, 1986; Weiner, 1982).

Number and Type of Appraisal Criteria

There is a surprising convergence of many appraisal theories with respect to some of the central dimensions postulated in almost all of the models. Yet there is controversy with respect to the number and type of the criteria (including the justification advanced) and the nature of the process involved. In those cases where only relatively few criteria or dimensions are proposed (based on theoretical concerns), the theory has roots in other domains, e.g. attribution theory (Weiner, 1982), or psychodynamic theory (de Rivera, 1977). Most other appraisal theorists postulate many more dimensions. These seem to have been derived generally in an eclectic fashion, apparently on the basis of an analysis of the semantic field constituted by the emotion terms in everyday language (see comparative reviews in Lazarus & Smith, 1988; Roseman, 1991; Scherer, 1988a).

My own suggestion, as expressed in the component process theory (Scherer, 1983, 1984a,b, 1986) is to posit relatively few basic criteria and to assume sequential processing of these criteria in the appraisal process. Table 1 shows the five major "stimulus evaluation checks" (SECs; including subchecks) which I consider to be sufficient to account for the differentiation of all major emotions. The table also gives an example of the patterns of results of the appraisal process that are expected to elicit specific emotions.

In principle, the issue of how many and what types of appraisal criteria or dimensions are necessary to explain the differentiation of emotion, can be addressed by empirical research. There are now quite a few empirical studies (Frijda, Kuipers, & ter Schure, 1989; Gehm & Scherer, 1988; Manstead & Tetlock, 1989; Reisenzein & Hofmann, 1990; Smith & Ellsworth, 1985, 1987) in which subjects have been asked to recall details for appraisal processes that elicited one or several emotions that they experienced in the past. Most of these studies address the question of the relative importance of particular criteria in the statistical discrimination of the reported emotion states and test hypotheses concerning the predicted emotion-specific appraisal patterns.

However, one of the major shortcomings of the work trying to study appraisal processes via subjects' verbal report, is to have to rely on information that is necessarily conscious and verbalisable. However, it is most unlikely that all, or even most, of the actual emotion-antecedent evaluation processes are conscious or easily verbalisable. All subcortical appraisal is unlikely to be available to consciousness. In addition, much of

TABLE 1
Sequence of Stimulus Evaluation Checks (SECs) proposed by Component Process Theory. (Reproduced from Scherer, 1986, p. 147)

1. *Novelty check.* Evaluating whether there is a change in the pattern of external or internal stimulation, particularly whether a novel event occurred or is to be expected.
2. *Intrinsic pleasantness check.* Evaluating whether a stimulus event is pleasant, inducing approach tendencies, or unpleasant, inducing avoidance tendencies; based on innate feature detectors or on learned associations.
3. *Goal/need significance check.* Evaluating whether a stimulus event is relevant to important goals or needs of the organism (relevance subcheck), whether the outcome is consistent with or discrepant from the state expected for this point in the goal/plan sequence (expectation subcheck), whether it is conducive or obstructive to reaching the respective goals or satisfying the relevant needs (conduciveness check), and how urgently some kind of behavioural response is required (urgency subcheck).
4. *Coping potential check.* Evaluating the causation of a stimulus event (causation subcheck) and the coping potential available to the organism, particularly the degree of control over the event or its consequences (control subcheck), the relative power of the organism to change or avoid the outcome through fight or flight (power subcheck), and the potential for adjustment to the final outcome via internal restructuring (adjustment subcheck).
5. *Norm/self compatibility check.* Evaluating whether the event, particularly an action, conforms to social norms, cultural conventions, or expectations of significant others (external standards subcheck), and whether it is consistent with internalised norms or standards as part of the self-concept or ideal self (internal standards subcheck).

the processing on the cortical level will occur so rapidly that it is difficult to imagine that detailed representations of the process will enter consciousness. Furthermore, the type of stimulus coding used in these appraisal processes might be quite different from the semantic categories available for linguistic description. Although some of the processing that did not enter consciousness as it was happening might be available for reconstruction from memory, much of what one is likely to obtain in studies using verbal report of past appraisal processes is probably constructed, based on established emotion schemata or prototypes (see Fehr & Russell, 1984; Philippot, 1992; Russell, 1991; Shaver, Schwartz, Kirson, & O'Connor, 1987; Scherer, 1992a).

If Leventhal and Scherer (1987) are correct in assuming that there are at least three different levels of CNS processing on which the stimulus evaluation checks can be performed, the use of verbal report would not provide an adequate strategy to test the appraisal process. One would expect that subjects, at most, have access to the conceptual level of processing. In trying to understand which features of appraisal one is likely to miss when relying exclusively on verbal report, it may be useful to turn to neuroscience work. In consequence, it is important to develop another type of access to emotion-antecedent appraisal processes, in addition to verbal report, to allow monitoring of appraisal processes that occur outside of awareness. It is understandable that, as described above, one pins one's hopes on modern neuromedical technology, evoked response potential measurement as well as advanced scanning and imagery techniques, to gain access to what happens inside the head without having to ask. If and when the quantum jump from mapping different kinds of cognitive activity to different contents of processing will be made, we might finally be able to get at appraisal without the coarse filter of verbal report (but see also the suggestion of using facial expression discussed later).

Neuropsychological work with brain-damaged patients might be used to examine the relative importance of different appraisal criteria. For example, one might study the effects of specific cognitive deficiencies with known neural origin on the emotional response systems. Such deficiencies affect processing of one or more of the appraisal criteria and should thus have a direct effect on the nature of the emotional experience available to the patient (if appraisal theories are correct and if compensation is not possible). I have suggested to use this approach to understand better emotional disorders by suggesting hypotheses on how malfunctioning of the processing of specific stimulus evaluation checks may produce different types of affective disturbance (Scherer, 1987).

If we were to be able to link specific neural damage to the malfunctioning of specific SECs, we might be able to demonstrate the relationship between specific cognitive appraisal criteria and the differentiation of emotion in a much more precise fashion. The study on anhedonia by Simons et al. (1982) provides an example for this type of approach. Similarly, a study by Yee and Miller (1988) on the modulation of fear in dysthymic patients illustrates the benefits of using pathology as a way to understand better emotional information processing. Unfortunately, so far the nosological approach to neural damage does not comprise features such as dysfunctions of goal directedness, inability to gauge coping potential, or difficulty to evaluate social norms. Most of the literature deals with major deficiencies in overall functioning such as aphasia, agnosia, hemineglect, or disturbances in emotional reactivity. If it were possible to include systematic tests of the ability to use basic cognitive appraisal criteria in clinical neuropsychological diagnosis procedures one might be able to establish whether this approach is promising or unrealistic.

Sequential vs. Parallel Processing

In most of the appraisal models referred to above no effort is made to conceptualise the nature of the evaluation *process*, the emphasis generally being placed on mapping the different emotions into the conceptual space generated by the appraisal dimensions that are proposed by the respective

Component Process Theory Predictions of SEC Outcome Effects on Different Organismic Subsystems (Component Patterning). (Reproduced from Scherer, 1984b, p. 45)

				Action System					
SEC Outcome	*Organismic Functions*	*Social Functions*	*Support System*	*Muscle-tone*	*Face*	*Voice*	*Instrumental*	*Posture*	*Locomotion*
Novelty									
Novel	Orienting Focusing	Alerting	Orienting response	Local changes	Brows/lids up Open orifices	Interruption Inhalation	Interruption	Straightening Raising head	Interruption
Old	Homeostasis	Reassuring	No change	No change	No change	No change	No change	No change	No change
Intrinsic pleasantness									
Pleasant	Incorporation	Recommend-ing	Sensitisation of sensorium	Slight decrease	Expanding orifices, "sweet face"	Wide voice	Centripetal movement	Expanding Opening	Approach
Unpleasant	Expulsion Rejection	Warning Decommend-ing	Defense response; desensitisa-tion	Increase	Closing orifices, "sour face"	Narrow voice	Centrifugal movement	Shrinking Closing in	Avoidance Distancing
Goal/need significance									
Consistent	Relaxation	Announcing stability	Trophotropic shift	Decrease	Relaxed tone	Relaxed voice	Comfort position	Comfort position	Rest position
Discrepant	Activation	Announcing activity	Ergotropic dominance	Increase	Corrugator	Tense voice	Task-dependent	Task-dependent	Task-dependent
Coping potential									
No control	Readjustment	Indicating withdrawal	Trophotropic dominance	Hypotonus	Lowered eyelids	Lax voice	No activity or slowing	Slump	No movement or slowing
High power/control	Goal assertion	Dominance assertion	Ergotropic balance Noradrena-line Respiration volume up	Slight decrease Tension in head and neck	Baring teeth Tensing mouth	Full voice	Agonistic movement	Anchoring body, lean forward	Approach
Low power/control	Protection	Indicating submission	Ergotropic dominance Adrenaline Peripheral vasocon-striction Respiration rate up	Hypertonus Tension in locomotor areas	Open mouth	Thin voice	Protective movement	Readiness for locomotion	Fast locomotion or freezing

theorist. From the very beginning of my struggle with emotion theory (Scherer, 1981), I have proposed that the appraisal criteria are processed in the fixed sequence in which they are listed in Table 1 (assuming that there is continuous sequential checking in very rapid succession). This postulate is based on the assumption that there is a definite logical order of checking the relevant criteria. In many cases, the results of prior stimulus evaluation checks are needed to evaluate properly a succeeding check. For example: You need to first realise that someone tries to slip surreptitiously into the parking space which you have been waiting for patiently during the last 10 minutes and that this seriously threatens your goal of being on time for an important appointment, before appraising how you will cope with that situation. You also need to know whether the other really means it and how strong he (or his car) is before deciding on a course of action.

The sequence hypothesis is motivated by the underlying assumption of the component process model that *each result of a stimulus evaluation check directly affects the state of all other components* (Scherer, 1984a, b, 1986). Table 2 shows a hypothetical listing of the "component patterning" to be expected as the result of specific SEC outcomes. Figure 1 illustrates the dynamics of this hypothetical process using facial expression as an example. On the left-hand side of the figure the presumed effect of four SECs on specific facial muscle groups is shown. The right-hand side demonstrates how the facial expression is sequentially and cumulatively changing with the effects of later SECs adding on to earlier effects (see Scherer, 1992b, for a more detailed account).

A similar sequential, cumulative process is expected to occur for all response modalities. It would not be appropriate to discuss the complex issues raised by this proposal in the context of this paper. Obviously, further details need to be specified before an empirical test of the notion of a sequential, cumulative process becomes feasible. In particular, it needs to be elaborated in which case a particular SEC result affects all or only some of the response modalities and in which case a successive SEC result pattern is required to trigger a particular change in a specific response modality. Suffice it to say that the basis for such predictions should be functional considerations about information processing and behavioural adaptation.

None of the other appraisal theorists subscribes to a sequential process of checking the various evaluation criteria proposed. Many emotion psychologists, in fact, seem to be very uncomfortable with the idea of sequential processing. I have encountered opposition on this point every time I have given a talk on my model—from 1979 on. Invariably it is suggested that it is more realistic to assume a parallel appraisal process. Recently, with growing interest in connectionism and massively parallel distributed systems I encounter even more objections.

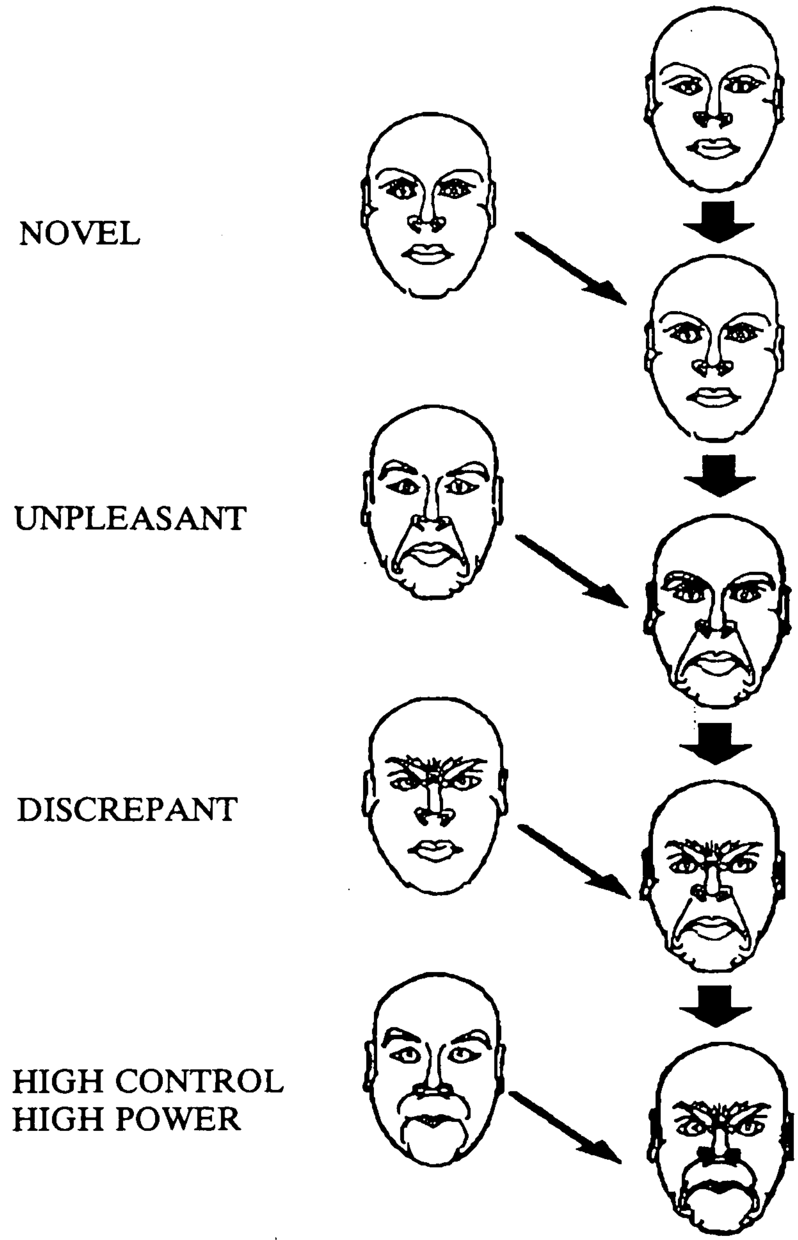

FIG. 1. Sequential, cumulative changes in facial expression as a result of specific SEC outcomes (as predicted by component patterning theory).

It is imperative, therefore, to subject the sequence model to empirical tests. If the component patterning assumptions outlined above are correct, physiological and expressive reactions should be useful indicators of individual cognitive or subcognitive evaluation checks and should thus lend themselves to test the sequence hypothesis. This notion is, of course, very similar to the assumption underlying the widely accepted idea that peripheral physiological changes index relatively simple patterns of stimulus processing (e.g. work on orientation and defence responses, e.g. Siddle, 1983, or on response patterning in general, see Stern & Sison, 1990). So far, this basic idea has been rarely extended to more complex cognitive evaluations or to the expressive domain.

However, the idea that thinking is expressed in facial expression is at least as old as the work of Duchenne (1876/1990) and Darwin (1872/1965). Since then, there have been few attempts to study the facial (or vocal) reflections of thought (but see de Sanctis, 1904; Schänzle, 1939). I have attempted to argue that vocal and facial expression may constitute a royal road to observe cognitive processes, particularly as far as emotion-antecedent appraisal is concerned (see Scherer, 1992b). If this is indeed the case, micro-analysis of facial movement with a high temporal resolution should allow us to test the sequence hypothesis as it is exemplified in Fig. 1 for the elicitation of an anger response. I have argued that vocal expressions might be used in a similar way to trace the sequential, cumulative process of emotional reaction (Scherer, 1988b).

Given the multiple factors determining facial and vocal expression, especially in social interaction, these response channels might be too noisy and possibly to undifferentiated to allow inference on SECs or other appraisal criteria and mechanisms. Alternatively, one could use continuous monitoring of autonomic and somatic response channels to assess the "continuous flow" of emotional processing (Cacioppo, Martzke, Petty, & Tassinary, 1988; see also Buck, 1985; Smith 1989 and footnote 3). Based on the "component patterning" approach described above, the author has developed a number of specific predictions of ANS and SNS responses to individual SEC results (see Table 2; further detail is provided in Scherer, 1983).

Obviously, the success of this type of approach depends on the strength and specificity with which the effects of central processing affect the periphery. Given that many emotion-relevant appraisals may occur at an

[3]We are actually conducting studies in this area, one using response latency time (as an indicator of the amount of processing required) in the domain of actual emotion experience (in collaboration with Arvid Kappas and Ursula Hess, measuring onsets of different systems in fine-grained psychophysiological measurement of reactions to a full feature film), and one using latency time measures in a computerised emotion recognition task.

unconscious level (see the discussion on direct pathways from the sensory end-organs to the amygdala below) it may not be very realistic to assume that emotion-antecedent cognitive processing has efferent effects on motor expression.

Therefore, we again turn to the neurosciences to search for pertinent research paradigms and methods that could be profitably used to obtain evidence bearing on the issue of sequential vs. parallel processing in emotion-antecedent appraisal. I will explore four possible avenues: neural networks, brain architecture, multi-layered processing, and evoked-response potentials.

Neural Networks

Neuroscience theory and research can provide a major contribution to the debate on sequential vs. parallel processing in emotion antecedent appraisal. Let us first turn to neural network theory and parallel distributed processing (PDP) models as these are frequently mentioned to make the case for parallelism. To begin with, the assumption of parallel distributed processing on a micro-level in no way rules out sequential or hierarchical processing on a more molar level (see Minsky, 1985; Minsky & Papert, 1969/1988). Damasio (1989, p. 40), in discussing his neural substrate of memory model referred to above, points out that the postulated recursive and iterative processes of time-locked retroactivation are both parallel, and, because of the many time phases involved, sequential.

PDP-based emotion model simulations could help to demonstrate the interplay between parallel and sequential processes in emotion differentiation. I have developed a modest demonstration of the utility of PDP models to investigate the sequence hypothesis: Using the IAC demonstration program in the Appendix of the McClelland and Rumelhart (1988) volume, I constructed a small network containing the basic five SECs (see Table 1) and the predicted effects on emotion elicitation (as encoded in the matrix of facilitatory and inhibitatory connections). As is to be expected, the activation of the theoretically predicted input patterns results in the desired activation of the respective output emotions. More interestingly, one can use the system to examine the predicted outcome of SEC results patterns that are not prototypical for "basic" emotions. Both the simultaneous activation of SECs that are not activated by external inputs and the specific pattern of activation of several output emotions (emotion blends) provide interesting insights and suggest hypotheses for further research. In particular, depending on the system parameters chosen (e.g. resting values, decay, alpha and gamma values), sequential activation of the input checks yields different results (corresponding more closely to theoretical prediction in many cases) than simultaneous (parallel) input.[4] More theoretically sophisticated neural network modelling and appropriate simulation runs could help to clarify the nature of the emotion-differentiating appraisal process.

Brain Architecture

Our theorising about the nature of the appraisal process, and eventual attempts at modelling a neural network paradigm, can be greatly advanced by taking into account the recent advances in the knowledge about anatomical structure and the pathways in emotion-relevant CNS functioning. As shown above, it is difficult to accept theoretically postulated functions or mechanisms that are not supported (or that are even contradicted by) the organisation of the substratum. Rather, our theorising should be directed and focused by recent insights on specific construction features of the nervous system.

LeDoux's (1987, 1989) work on the brain mechanisms involved in evaluating the affective significance of cognitive processing is most pertinent in this respect. His elegant work on identifying functional pathways in perception and emotional learning in the rat has provided evidence for the existence of a direct thalamo-amygdala projection. Complex stimuli are processed in thalamic sensory nuclei and relayed to neocortical regions for detailed perceptual analysis and synthesis. However, simpler features of these stimuli activate thalamic cells that communicate directly with the amygdala and can provide a rudimentary assessment of the affective significance of these stimuli. In this sense, the amygdala is seen to serve a general homeostatic function, evaluating the significance of inputs from exteroceptive and interoceptive sources and rapidly initiating behavioural and visceral responses accordingly.

I argue that the first two SECs, novelty (abruptness of onset) and intrinsic pleasantness of a stimulus, are such simple features that might be processed very rapidly because they access the parallel sensory pathways to the amygdala. They would occur at the very beginning of the theoretically proposed sequence of SECs because:

- They originate early in the sensory processing sequence.
- They use shorter pathways.
- The thalamic cells in which the projection to the amygdala originates have relatively weak tuning properties (see LeDoux, 1987, p.436)

[4]A print-out of the control and data files necessary to run the emotion simulation using the IAC program provided by McClelland and Rumelhart (1988) can be obtained by writing to the author.

These features could also explain the evidence that Zajonc (1980) adduces to argue for a primary affective processing system. This is all the more so because many of his examples involve stimuli that are likely to involve the novelty and intrinsic pleasantness checks. The evaluation of the affective significance of sensory stimuli via limbic neurons (e.g. for novelty and pleasantness) is likely to occur unconsciously. If we knew more about the structures that mediate processing of the different appraisal dimensions we might also have a better handle on the thorny issue of awareness and consciousness in emotional processing—particularly with respect to subjective feeling state.

The sequence argument is also based on the notion that the order of the SECs in microgenesis parallels the order in the acquisition of the capacity to perform the SECs in ontogenetic and phylogenetic development (Scherer, 1984a;b). This assumption would seem to be supported by LeDoux's (1989, p. 281) suggestion that the evolutionarily and developmentally primitive thalamo-amygdala connections may be very important in early life prior to the maturation of the neocortex and the hippocampus. There is evidence that such evolutionarily primitive sensory channels are used by many primates for the evaluation of stimuli with affective significance (LeDoux, Farb, & Ruggiero, 1990).

Multi-layered Processing

It should be noted that the preceding discussion does not imply that subcortical structures allow very extensive or sophisticated interpretative evaluation. Obviously, only relatively simple stimulus features can be processed on these levels. As Leventhal and Scherer (1987) have attempted to show, the strength of the human appraisal system resides in the fact that different levels of evaluation are available and that processing can be adapted to the nature of the stimulus or the interpretative needs of the organism.

The suggestion of a multi-layered process of appraisal is supported by LeDoux's (1989) demonstration that the amygdala and the hippocampus have differential functions in evaluating the affective significance of stimulation. The direct thalamo-amygdala projection allows crude but very rapid processing, corresponding to the lowest, sensori-motor level of processing in the Leventhal and Scherer (1987) model. The hippocampus is much slower to respond to sensory inputs but these are integrated across several modalities in complex association cortex treatment before reaching the hippocampus which allows far more sophisticated processing. This pathway might correspond to the schematic level in Leventhal and Scherer's model, because it could be assumed that the association cortex uses schema-like patterns in its preprocessing of the inputs across modalities.

The assumption of multi-layered, sequential "cascades" of stimulus appraisal is supported by recent work, conducted in LeDoux's laboratory, on the acoustic connections of the lateral amygdala in the rat. These studies show that sensory information relayed by the ventral and medial nucleus of the medial geniculate body reaches the lateral amygdala directly and at different lag intervals after preprocessing by different structures including the perirhinal cortex (LeDoux, personal communication).

Thus, evidence on central nervous system structures and pathways can help psychological theorising by providing information on the biological constraints. Such evidence is particularly pertinent for issues concerning sequences and timing of the processing of different types of information. As the research on the respective timing and patterning of the orienting and defence responses has shown (Siddle, 1983; Stern & Sison, 1990), autonomic indicators can be used for fine-grained measurement. Similarly, facial muscle movement (possibly using EMG; Cacioppo, Petty, Losch, & Kim, 1986) may well be considered for this task.

Monitoring Evoked-response Potentials

Brain research, in addition to stimulating theoretical development, can provide measures that directly tap central processing activity. One could envisage using EEG, PET scans, and other methods with high temporal resolution (see earlier) to test empirically the sequence hypothesis.

Coles et al. (1990) specifically mention the utility of evoked response potential (ERP) measurement to study emotion-antecedent appraisal processes and review several studies which demonstrate the ERP applications in affectively toned emotion processing. The work by Hansen and Hillyard (1983) may illustrate potential paradigms that might be adapted for use in studies on appraisal. These researchers presented stimuli representing two different characteristics with known ERP patterns, to measure which of the two patterns occurs first in order to test sequential (early preselection) vs. parallel (full analysis, late selection) theories. If standard ERP patterns for novelty, pleasantness, and unexpectedness can be empirically demonstrated, one could imagine to use similar paradigms to test the sequence hypothesis, at least in a partial fashion. Unfortunately, it is to be expected that many of the more complex evaluation checks, such as goal/plan conduciveness or coping potential, depend on stimulus/organism interaction and thus may not show well-defined ERPs as in the case of stimulus-specific characteristics. Yet, the potential to directly access the central processes reflecting emotion-antecedent appraisal is most auspicious, especially with respect to an analysis of extremely rapid dynamic sequences of appraisal, as they have been postulated by the component process model. The work by Johnston, Miller, and Burleson (1986) on ERP patterns involved in the processing of emotional stimuli demonstrates the use of this method to disentangle very fine-grained sequences in stimulus processing.

5. DIFFERENTIAL PATTERNING OF THE EMOTIONS

Although there is controversy surrounding the nature of the emotion-cognition interface and the nature of emotion-antecedent appraisal processes, few would doubt that the emotions are differentiated on a cognitive level. The very existence of a multitude of verbal emotion labels with subtle differences in meaning and connotation makes it difficult to deny the existence of differentiated states at least with respect to conscious subjective feeling.

Peripheral Differentiation and Specificity

However, much controversy surrounds the question, on what other levels, if any, the emotions are differentiated. Duffy's (1941) extreme position, relegating differences between emotions to variations in arousal is no longer fashionable. Yet, vestiges of the idea that emotions may not be differentially patterned except on the level of cognitive interpretation can be found in a quite a number of modern emotion theories. The Schachter and Singer theory of emotion (1962) which has reigned supremely over the few emotion pages in psychology textbooks, as well as Mandler's (1984) reformulation of the underlying self-attribution hypothesis, defend the idea that it is only through post-arousal cognitive inferences that emotions are differentiated. Many dimension theories (e.g. Russell, 1980), although they are rarely explicit about the components of emotion, would consider differentiation only with respect to the relative position of the emotions on two, or maximally three, continuous dimensions. In consequence, the controversy between differentialist and dimensionalist approaches is one of the most lively ones in the field. It is far from being resolved. The lack of conclusive evidence, particularly with respect to the physiological domain (see Scherer & Wallbott, submitted) continues to encourage sterile repetition of unsubstantiated opinions.

The definition of emotion I propose, i.e. synchronised state changes in all organismic subsystems in response to a highly pertinent event, clearly postulates a direct correspondence between the respective changes in the contributing systems, and thus a highly integrated differential patterning of the different emotions which involves all response modalities. In other words, not only should the different emotions be accompanied by changes in the states of all subsystems, the patterns of changes should in addition be closely interrelated. Most theorists endorsing a psychobiologically oriented, functional view of emotion postulate a similar process of emotion differentiation. In this tradition, emotion is seen as an integrated response to a relevant event, requiring an appropriate adaptation on all levels of organismic functioning.

Scherer and Wallbott (submitted), reporting data on self-reports of actually experienced emotions (joy, fear, anger, sadness, disgust, shame, and guilt) from 2921 respondents in 37 countries, find a remarkable degree of differential patterning for all response domains. These emotion-specific reaction patterns are largely universal across the many countries studied. Although these self-report data generally support a differentialist position, they are obviously too imprecise to allow an investigation of the process of emotion differentiation, particularly with respect to the synchronisation of system states within very short time periods. Furthermore, opponents of the differentialist view are likely to argue that self-report data reflect little more that socially constituted cognitive representations of emotion differences (Philippot, 1992; Rimé, Philippot, & Cisamolo, 1990; but see Scherer, 1992a; Scherer & Wallbott, submitted, for a rebuttal).

Multi-modal Measurement

One would think that it should not be too difficult to settle this debate on the basis of empirical evidence from experimental studies. The induction of different emotions in the laboratory where, in principle, all response modalities (CNS and ANS changes, facial, vocal, and bodily expression, subjective feeling, and cognitive inferences) are measurable should allow to determine to what extent the emotion inductions affect all or only some modalities, and whether the change patterns are interrelated. Unfortunately, such studies do not exist. Although many different induction techniques have been used—situation and interaction manipulation, imagination, role playing, film viewing, music, etc.—it is doubtful whether the respective investigators have succeeded in producing states that are equivalent to powerful, real-life emotion experiences (which is what our theories are mostly about). Furthermore, in only a handful of studies at most have the investigators attempted to measure more than a single response modality (generally sticking to the dependent variable domain for which the respective laboratory is specialised).

However, even if the ethical and practical problems of inducing powerful, real emotions in the laboratory and of acquiring the necessary competence for complex measurements in many response domains could be solved, the data might still not yield conclusive evidence. This is due to the serious problems concerning the definition and the measurement of synchronisation or interrelationships of changes in different response domains. For example, in a large-scale study of cognitive and emotional stress, we (Tolkmitt & Scherer, 1986; Wallbott & Scherer, 1991) measured cognitive appraisal and subjective feeling (via self-report), facial expression (using the Facial Action Coding System: Ekman & Friesen, 1978), vocal expression (using digital analysis of acoustic features of the voice), as well as a number of physiological response systems (monitoring heart rate, skin conductance, respiration, and EMG). Even though quite a few of these parameters allowed to differentiate various cognitive and emotional states, it was difficult to establish the interrelationships between the observed change patterns in the different response modes (see Wallbott & Scherer, 1991). One of the reasons is that the different systems do not have the same response characteristics, especially with respect to onset latency, intensity peaking, and decay characteristics.

Brain research (in conjunction with psychophysiological monitoring of peripheral responses) could be of help to address this problem. By studying the pathways and the processing speeds for different systems, it might be possible to specify procedures to study intersystem synchronisation in a more realistic fashion, by allowing for specified lags or by defining appropriate analysis units. Given the complexity of the task ahead, there is an obvious need for a close collaboration between emotion psychologists, specialists in peripheral and central response measurement, neuroscientists and statisticians specialising in multivariate time series analysis.

Such a collaboration would need to be based on appropriate data, requiring many more multi-modal measurement approaches than are currently practised in emotion research. Also, so far only very few studies in this area measure the dependent variables in such a way that they become amenable to the type of fine-grained analysis needed for this purpose (most research to date uses fairly large integration periods or aggregate measurement). Similarly, neuropsychological research on affect disturbance all too often uses only a limited set of tasks and assessment procedures and rarely includes precise measurement of physiological or expressive variables that could be helpful in understanding the pathology in terms of processing and patterning. Multi-modal measurement in the assessment of patients, although expensive and time-consuming, could help to allow more direct comparisons of neuropsychological work on affect disturbance and experimental studies using emotion induction in normal populations.

6. ENTRY POINTS AND INTERSYSTEM FEEDBACK

One of the major foci of controversy in emotion psychology has been the so-called facial feedback hypothesis, the notion that strong, uncontrolled facial expression of an emotion is likely to feed back to other component systems (e.g. to increase the intensity of the subjective feeling associated with the emotional episode). This notion is in direct opposition to a catharsis position, i.e. the idea that draining emotional energy in one system will also reduce the intensity of arousal in other systems. Contrary to other areas of debate in emotion psychology there have been quite a few pertinent experimental studies in this area although the interpretation of the data is strongly debated (Buck, 1980; Laird, 1974; Rutledge & Hupka, 1985; Strack, Martin, & Stepper, 1988; Tourengeau & Ellsworth, 1979; Zajonc, 1985).

A similar debate has been spurned recently by findings on emotion induction via directed facial action (DFA) reported by Ekman, Levenson, and their collaborators (Ekman, Levenson, & Friesen, 1983; Levenson, Ekman, & Friesen, 1990). They have shown that subjects that are led via neutral instructions to successively innervate various facial muscles resulting in configurations representative of the expressive patterns of different emotions, will exhibit some of the physiological symptoms and tend to experience the subjective feeling specific to the respective emotion. In spite of the replicated experimental evidence reported by these researchers, the possibility that emotions can be produced by voluntary muscle innervation without any emotion-related imagery intervening in the process is not yet generally accepted.

All of the different positions described above, as well as most of their critics, part from the assumption that emotions consist of several component systems which are multiply interrelated. The controversies concern the nature and dynamics of these interconnections and the possibility of each of these systems serving as an entry point to activate an integral emotional state.

Intersystem Activation Spread

My own view, as expressed in the component process model, is that the subsystems are indeed multiply interconnected and that both feedback and feedforward processes play an extremely important role in the process of subsystem synchronisation during an emotion episode. I have not ventured an attempt to propose details of the structure of these interconnections but I am increasingly seduced by neural network modelling as a possible approach to understanding the dynamics of the emotion subsystem interconnections. Most of the effects described earlier can be explained by spread in activation networks without the need to postulate relatively rigid innate programmes for specific emotions (as proposed by discrete emotion theorists). Although I believe that cognitive appraisal is the privileged entry point to the emotion system and the one that is likely to set off the synchronisation process in many cases, I would not doubt that, assuming that activation spread networks form the underlying structure, other subsystems could also serve as entry points.

Because all of the subsystems involved in an emotional episode are controlled by the CNS, activation spreading from the periphery to the centre could entail a general activation spread across the CNS, producing the synchronisation of the pertinent control sites mentioned earlier. Such a model could easily encompass many of the instances where emotion induction via peripheral activation has been reported—starting with Schachter and Singer's experimental procedure (1962; but see Reisenzein, 1983, for a discussion of the replication problems) to Ekman et al.'s (1983) technique using the Directed Facial Action Task. There are obvious implications for clinical application. Most relaxation therapies (Gellhorn, 1970; Jacobson, 1964; Schultz, 1966) have essentially suggested to change the centre (mood states) by manipulating the periphery (reducing muscle tension). Similarly, psychoactive drugs may affect central structures directly but probably also work via direct effects on the periphery and resulting spread to the centre.

A model based on activation spread in a process of synchronisation of associated brain control centres and multiple feedback and feedforward loops involving the periphery could easily accommodate most of these phenomena. However, it is not quite obvious how much of a *partial* activation is required to elicit *total* central synchronisation. One possibility would be to argue for innate programmes, as argued by Tomkins (1984) and other discrete emotion theorists, by reconceptualising these as activation and synchronisation patterns that take a lawful course after a significant partial has been activated. Another possibility is that the partial activation and synchronisation activates emotional memory traces, as suggested above for emotion memory retrieval. One interesting implication of these different conceptualisations is that a memory retrieval interpretation would suggest that subjects should react differently to peripheral entry point stimulation (depending on their differential emotion memories), whereas an innate programme explanation would need to postulate that the same biologically based, universal patterns are activated for all subjects.

Neural Architecture Constraints

Clearly, progress with respect to understanding the problem of subsystem interconnection and entry points depends on close collaboration with the neurosciences. We need more data on interconnections, pathways, arousal spread, inhibition, etc. with respect to the process of emotion. Unfortunately, so far only relatively few neuropsychologists have shown a central interest in emotion (e.g. Arnold, 1960; Gray, 1987; LeDoux, 1987; Panksepp, 1982). It is to be hoped that their number will increase and that they will be willing to try to find a common level of discourse with emotion psychologists. Similarly, until now experts on connectionist network simulation have shown little interest in the complex phenomenon of emotion. Even though connectionist models of the emotion process would be highly formal and abstract to begin with they might provide important insights for theorising and research in the psychology of emotion.

Further information about structural constraints with respect to interconnections and pathways as well as connectionist simulations will be useful but certainly not decisive to settle the long-standing controversies concerning subsystem interconnection and particularly the causal chaining to and from central and peripheral systems. All the major debates in the area, e.g. the James-Cannon controversy (see Frijda, 1986), the debate on the Schachter-Singer (1982) hypothesis, and partly also the Lazarus-Zajonc debate (see Leventhal & Scherer, 1987) have focused on this issue. If a connectionist model were to prove useful in this domain, the debate might lose its either/or nature and become more an issue of multiple interconnection and diffuse spread with one or the other subsystem occasionally taking the lead.

Neuropsychological work with patients may well help to arrive at a better understanding of the complementary relationships between the systems that are involved. For example, LeDoux (1987) describes tests with split-brain patients whose capacity for speech processing is almost entirely restricted to the left hemisphere. If a command is given to the right hemisphere (where there is sufficient capacity left to understand simple motor commands), the commanded action is produced but the left hemisphere does not know why. When asked why they perfomed the respective act, these patients give explanations based on context, or inference from their behaviour (see also Gazzaniga, 1988).

LeDoux (1987) uses this and similar experiments to argue for a position of multiple feedback between central and peripheral systems. Starting from the assumption that emotion is a relatively recent acquisition in phylogenesis he proposes that information about the effective significance of certain events and stimuli reaching the cognitive system includes feedback: (1) from peripheral muscles and other organs active during expression; (2) from the observation of one's own behaviour and the situational context, as well as, more directly; (3) from limbic neurons that perform a rudimentary coding of emotional significance. There are interesting parallels with the position advanced by Nisbett and Wilson (1977) who argue that prototypes and scripts serve to complement our information about the emotional significance of our own behaviour.

CONCLUSION

I have attempted to cover some of the currently debated issues in the psychology of emotion that might benefit from evidence obtained in the neurosciences. Of course, there are many other issues that might similarly benefit. For example, one important controversy opposes advocates of a biological, phylogenetically continuous nature of emotion, arguing for universality of emotional phenomena with a regulating function for culture (Ekman, 1972, 1984, 1992), to advocates of a relativist view who argue that sociocultural factors actually constitute or construct emotion (Averill, 1980; Greenwood, 1991; Harré, 1986; Hochschild, 1983; Lutz, 1988). The controversy between universalists and cultural relativists or constructionists is difficult to settle in the absence of appropriate evidence, particularly as most of the anthropological data on cultural differences is restricted to verbal labelling (see Mesquita & Frijda, in press; Scherer & Wallbott, submitted, for a review of the issues).

Although there is strong evidence for a psychobiological, universal basis of the emotion mechanism (Ekman, 1992), there are also many examples (including good empirical evidence) for a powerful impact of cultural factors on: (1) elicitation through specific antecedent situations; (2) appraisal and differentiation (due to the cultural specificity of values and goals); (3) learning during the socialisation process; (4) regulation and control of the response modalities; (5) differences in emotion-consequent behaviour; and (6) differences in social representation, labelling, and communicative sharing (Scherer & Wallbott, submitted; Scherer, Wallbott, Matsumoto, & Kudoh, 1988).

The attempt to mediate between universalist and relativist positions could be greatly advanced by evidence from the neurosciences. For example: One could establish whether there is any evidence for cultural or racial differences in structures and/or processes in the domain of emotion or emotion-relevant domains of CNS functioning. Of particular interest are the extent and the form of the malleability of the biological emotion systems, as far as central processes are concerned and the role of learning experiences and situational constraints.

The comparative perspective and the study of phylogenetic continuity of central nervous mechanisms are important discovery procedures in brain research. There should also be a role for cross-cultural comparison. It would be interesting to determine to what extent comparable lesions in well-defined areas of the brain seem to affect the emotional life of patients in different cultures. Cross-cultural work on depression has shown some interesting differences, admittedly linked in part to differences in medical nosology (Sartorius, 1987). If LeDoux's suggestion about the construction of experience from proprioceptive and situational feedback is correct, one should find instructive differences between groups of patients in different cultural and subcultural contexts. Such data would constitute invaluable sources of information for the psychology of emotion.

It would be easily possible to continue the list of controversies that stand to benefit from contact with brain research. One might also turn the issue around: How much can the neurosciences benefit from emotion research, trying to deal with some of the complex issues under scrutiny in this domain? One could make a case that many of the issues raised above provide strong challenges for many different facets of neuroscience research and may well suggest interesting paradigms for looking at very complexly integrated structures and networks.

This paper does not attempt to answer any questions. It has tried to sharpen some of the perennial issues of debate in the psychology of emotion and to examine whether evidence from the neurosciences might help to settle the issues. It would be gratifying if the discussion were to generate some interest in neuroscience approaches for those emotion psychologists generally reticent to deal with the substratum, and if it were to motivate some neuroscientists to get involved in the fundamental puzzles of emotion psychology. What would be most desirable, of course, is the intensification of the collaboration between emotion psychologists and neuroscientists, going beyond polite citations of the major references in the respective areas and dealing hands-on, both conceptually and empirically, with the current issues in research.

Insisting that interdisciplinarity is essential in building bridges between the psychology and the neurobiology of cognition, Eimas and Galaburda (1989) spell out the major task for this collaboration: identifying (1) the *binding* mechanisms, i.e. the reconstitution of entities from parts that are spatially segregated and distributed in the nervous system; and (2) the *bonding* mechanism, the unification of sequential experience into whole events. I have attempted to show that emotion psychology faces exactly the task: Conceptualising the sequential multi-componential process that constitutes emotion episodes and operationalising the bonding of specific emotional experiences in the flow of consciousness. The neurosciences are well equipped to contribute to this daunting enterprise.

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