

# Anxiety and Cognitive Performance: Attentional Control Theory

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Attentional control theory is an approach to anxiety and cognition representing a major development of Eysenck and Calvo's (1992) processing efficiency theory. It is assumed that anxiety impairs efficient functioning of the goal-directed attentional system and increases the extent to which processing is influenced by the stimulus-driven attentional system. In addition to decreasing attentional control, anxiety increases attention to threat-related stimuli. Adverse effects of anxiety on processing efficiency depend on two central executive functions involving attentional control: inhibition and shifting. However, anxiety may not impair performance effectiveness (quality of performance) when it leads to the use of compensatory strategies (e.g., enhanced effort; increased use of processing resources). Directions for future research are discussed.

*Keywords:* anxiety, attention, inhibition, shifting

In this article, we are concerned primarily with the effects of anxiety on cognitive performance. The emphasis is on anxiety within normal populations rather than within clinically anxious ones, and there is a focus on individual differences in anxiety as a personality dimension, typically assessed by measures of trait anxiety such as Spielberger's State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Nevertheless, individual differences in more specific measures (e.g., test anxiety; Spielberger et al., 1980) are also considered, as are studies in which anxiety is manipulated experimentally (e.g., via evaluative instructions; competitive situations).

Anxiety is an aversive emotional and motivational state occurring in threatening circumstances. State anxiety (the currently experienced level of anxiety) is determined interactively by trait or test anxiety and by situational stress (see Eysenck, 1992). It can be conceptualized as "a state in which an individual is unable to instigate a clear pattern of behavior to remove or alter the event/object/interpretation that is threatening an existing goal" (Power & Dalglish, 1997, pp. 206–207). Individuals in an anxious state frequently worry about the threat to a current goal and try to develop effective strategies to reduce anxiety to achieve the goal. Anxiety is of importance within the field of cognition and perfor-

mance because it is often associated with adverse effects on the performance of cognitive tasks (see Eysenck, 1992, for a review).

The main focus of the theoretical predictions in this article is the effects of anxiety on cognitive tasks, in particular those placing significant demands on cognitive resources. The emphasis is on short-lasting cognitive tasks performed under laboratory conditions. Such tasks permit the identification of the cognitive processes underlying performance under controlled conditions.

The structure of the article is as follows. Initially, we discuss processing efficiency theory to provide a background to the theoretical context. Then we present the assumptions of the attentional control theory. Next, we evaluate the evidence relating to this theory's major hypotheses, and finally, we discuss future research directions.

## Processing Efficiency Theory

The theory developed here represents a major extension of the processing efficiency theory put forward by Eysenck and Calvo (1992), itself an extension of the theoretical views of Eysenck (1979). As such, we first briefly consider processing efficiency theory. The most important distinction in processing efficiency theory is between effectiveness and efficiency. *Effectiveness* refers to the quality of task performance indexed by standard behavioral measures (generally, response accuracy). In contrast, *efficiency* refers to the relationship between the effectiveness of performance and the effort or resources spent in task performance, with efficiency decreasing as more resources are invested to attain a given performance level. Ways of measuring resource utilization are discussed later. Negative effects of anxiety are predicted to be significantly greater on processing efficiency than on performance effectiveness.

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### Assumptions

Processing efficiency theory rests on two major assumptions. First, worry is the component of state anxiety responsible for effects of anxiety on performance effectiveness and efficiency. Worry or self-preoccupation is characterized by concerns over evaluation and failure and expectations of aversive consequences (e.g., Borkovec, 1994). Worry is activated in stressful situations (especially in test, evaluative, or competitive conditions) and is most likely to occur in individuals high in trait anxiety (e.g., see Eysenck, 1992, for a review). Worry has two effects. One effect involves cognitive interference by preempting the processing and temporary storage capacity of working memory. The worrisome thoughts consume the limited attentional resources of working memory, which are therefore less available for concurrent task processing. The other effect involves increased motivation to minimize the aversive anxiety state. This function is accomplished by promoting enhanced effort and use of auxiliary processing resources and strategies. Thus, potential performance impairments caused by the preemption of working memory resources can be compensated for. If auxiliary processing resources are available, impaired performance effectiveness is less likely to occur but at the cost of reduced efficiency. If these resources are unavailable, then performance effectiveness will be impaired.

The second assumption concerns the mechanisms and components of working memory affected by anxiety. Processing efficiency theory is based on the tripartite working memory model (Baddeley, 1986), since expanded into a four-component model (Baddeley, 2001). According to the original model, the limited-capacity working memory system consists of (a) a modality-free central executive involved in the processing of information and having self-regulatory functions (e.g., performance monitoring, planning, and strategy selection); (b) a phonological loop for the rehearsal and transient storage of verbal information; and (c) a visuospatial sketchpad for the processing and transient storage of visual and spatial information.

It is assumed that the main effects of worry (and, more generally, of anxiety) are on the central executive. Accordingly, adverse effects of anxiety on performance and efficiency should be greater on tasks imposing substantial demands on the processing and storage capacity of working memory (especially the central executive). Worrisome thoughts interfere with this processing-and-storage function, and there is an additional burden on the self-regulatory mechanism inhibiting such thoughts and producing auxiliary processing activities. Detrimental effects of anxiety are also expected on the phonological loop rather than on the visuospatial sketchpad because worry typically involves inner verbal activity rather than imagery representations (Rapee, 1993).

### Theoretical Limitations

Some of the theoretical assumptions of processing efficiency theory lack precision, explanatory power, or both. In addition, the scope of the theory is insufficient to account for several findings. Specific examples are itemized below.

First, the notion that anxiety impairs the processing efficiency of the central executive is imprecise because it fails to specify *which* central executive functions are most adversely affected by anxiety. For example, E. E. Smith and Jonides (1999) argued that the

central executive fulfills five functions: switching attention between tasks; planning subtasks to achieve a goal; selective attention and inhibition (i.e., focusing attention on relevant information and processes and inhibiting irrelevant ones); updating and checking the contents of working memory; and coding representations in working memory for time and place of appearance. It is unclear from processing efficiency theory whether anxiety affects some (or all) of these functions.

Second, there are no theoretical assumptions concerning the effects of distracting stimuli on anxious individuals. This is important given the accumulating empirical evidence that the performance of anxious individuals is more impaired by distracting stimuli than is that of nonanxious individuals (e.g., Calvo & Eysenck, 1996; Eysenck & Graydon, 1989; Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998; see Eysenck, 1992, for a review).

Third, processing efficiency theory focuses exclusively on cognitive tasks involving neutral or nonemotional stimuli (defined in terms of their content). However, the performance of anxious individuals is more affected by threat-related stimuli (especially social threat) than that of nonanxious ones. For example, adverse effects of distracting stimuli on the performance of anxious individuals compared with nonanxious ones are often greater when the distracting stimuli are threat related rather than neutral (e.g., Egloff & Hock, 2001; Eysenck & Byrne, 1992; Keogh & French, 2001; Mogg et al., 2000).

Fourth, processing efficiency theory does not directly consider circumstances in which anxious individuals might outperform non-anxious ones. In fact, there are several studies (mostly involving paired-associate learning) in which the high-anxious group outperformed the low-anxious group (e.g., Byrne & Eysenck, 1995; Spence, Farber, & McCann, 1956; Spence, Taylor, & Ketchel, 1956; Standish & Champion, 1960).

### Attentional Control Theory: Assumptions

In this section, we present the attentional control theory. The literature has used the term *control* in various ways. The sense in which we use it here is the same as that of Yantis (1998), who focused on whether attention is controlled or determined in a goal-driven, top-down fashion or in a stimulus-driven, bottom-up fashion. The theory is not a general theory of attentional control but rather is concerned with attentional control in the context of anxiety and cognitive performance. As its name suggests, the theory is not designed to apply to all effects of anxiety on the cognitive system. For example, there is much evidence suggesting that anxiety influences explicit and implicit memory (see J. M. G. Williams, Watts, MacLeod, & Mathews, 1997; Rinck & Becker, 2005). Such effects are somewhat inconsistent and lie outside the theory's scope.

Attentional control theory represents a major development of the previous processing efficiency theory, building on its strengths and addressing its limitations. The key assumption that there is an important distinction between processing efficiency and performance effectiveness is central to attentional control theory. However, this theory extends the scope of the previous theory and is more precise about effects of anxiety on the functioning of the central executive. The development of attentional control theory has been much influenced by the theoretical ideas and empirical research of several researchers (e.g., Derryberry & Reed, 2002;

Fox, 1993; Fox, Russo, & Dutton, 2002; Hopko et al., 1998; Mathews & Mackintosh, 1998).

The most general assumption within attentional control theory is that effects of anxiety on attentional processes are of fundamental importance to an understanding of how anxiety affects performance. Why is this the case? Power and Dagleish (1997) assumed that anxiety is experienced when a current goal is threatened, a general assumption consistent with much empirical evidence. Threat to a current goal causes attention to be allocated to detecting its source and to deciding how to respond. Some support for the assumption that anxiety facilitates the detection (and processing) of danger or threat comes from studies on attentional bias (e.g., Egloff & Hock, 2001; Eysenck & Byrne, 1992; Fox et al., 2002; Mogg & Bradley, 1998; Mogg et al., 2000; Wilson & MacLeod, 2003), in which anxious individuals preferentially attend to (or more often preferentially have delayed disengagement from) threat-related stimuli in the presence of neutral stimuli.

### *Attentional Control*

The assumption that anxiety increases the allocation of attention to threat-related stimuli (and to deciding how to respond in the anxiety-provoking circumstances) means that anxiety typically reduces attentional focus on the current task unless it involves threatening stimuli. More specifically, anxiety impairs attentional control, a key function of the central executive. It follows that anxious individuals preferentially allocate attentional resources to threat-related stimuli whether internal (e.g., worrisome thoughts) or external (e.g., threatening task-irrelevant distractors).

High levels of worry are often associated with low levels of performance (see Sarason, 1988, for a review). However, there are several studies in which high-anxious participants reported significantly more worry than low-anxious ones, but the two groups did not differ in performance (e.g., Blankstein, Flett, Boase, & Toner, 1990; Blankstein, Toner, & Flett, 1989; Calvo, Alamo, & Ramos, 1990; Calvo & Ramos, 1989). According to attentional control theory, this pattern could occur because worry impairs efficiency more than performance effectiveness. However, most of the studies in which worry has been considered have limitations. Worry is seldom manipulated explicitly, it is often assessed only retrospectively, and the relationship between worry and attention has not been investigated systematically. In view of these limitations, relatively little research on worry, anxiety, and performance has provided a direct test of the theory.

There is a further assumption that anxiety also impairs attentional control even when no threat-related, task-irrelevant stimuli are present. When an individual perceives him- or herself to be under threat and so experiences anxiety, it is potentially dangerous to maintain very high attentional control to a specific stimulus or location. Instead, the optimal strategy is to allocate attentional resources widely, thereby reducing attentional control with respect to any ongoing task.

The theoretical assumption that anxiety impairs attentional control can be related to the view (e.g., Corbetta & Shulman, 2002; Posner & Petersen, 1990) that there are two attentional systems. For example, Corbetta and Shulman distinguished between a goal-directed attentional system influenced by expectation, knowledge, and current goals and a stimulus-driven attentional system responding maximally to salient or conspicuous stimuli. The goal-

directed attentional system is involved in the top-down control of attention (e.g., via attentional set). It resembles the anterior attentional system proposed by Posner and Petersen and the cognitive control system identified by Miller and Cohen (2001). There are important commonalities among these three systems (e.g., they are involved in top-down control of attention; they are centered in the prefrontal cortex), and these commonalities provide a framework for attentional control theory.

The stimulus-driven attentional system identified by Corbetta and Shulman (2002) is involved in the bottom-up control of attention and "is recruited during the detection of behaviorally relevant sensory events, particularly when they are salient and unattended" (pp. 201–202). This system includes the temporoparietal and ventral frontal cortex and resembles Posner and Petersen's (1990) posterior attentional system. In practice, the goal-directed and stimulus-driven attentional systems frequently interact in their functioning (see Pashler, Johnston, & Ruthroff, 2001, for a review).

According to attentional control theory, anxiety disrupts the balance between these two attentional systems. It is associated with an increased influence of the stimulus-driven attentional system and a decreased influence of the goal-directed attentional system. This involves bidirectional influences of each system on the other. For example, anxiety affects the stimulus-driven attentional system via automatic processing of threat-related stimuli (e.g., Fox, Russo, & Georgiou, 2005), thereby decreasing the influence of the goal-directed attentional system. In addition, reduced influence of goal direction on attentional processes means that such processes are more affected by salient and conspicuous stimuli. All these effects of anxiety should be greater when anxiety levels are especially high (e.g., under stressful conditions).

The two attentional systems identified by Corbetta and Shulman (2002) and Posner and Petersen (1990) provide a valuable framework within which to consider the effects of anxiety on cognitive processing. However, this theoretical approach is a general one, and higher level functions such as goal-directed planning are difficult to define operationally. The position is similar with respect to the central executive. As discussed earlier, it is oversimplified to regard the central executive as unitary, and so hypotheses framed in terms of the central executive tend to be general and vague.

What is needed is a theoretical approach focusing on lower level functions that are related to the goal-directed attentional system and to the central executive and that can be operationalized. In an impressive contribution, Miyake et al. (2000) used latent-variable analysis to identify the basic control functions of the central executive, basing their selection of tasks on lower level functions that had previously been proposed for the central executive by various theorists (e.g., Baddeley, 1996; E. E. Smith & Jonides, 1999). Miyake et al. identified three major functions:

1. Inhibition: "One's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary" (p. 57); this involves using attentional control to resist disruption or interference from task-irrelevant stimuli or responses.
2. Shifting: "Shifting back and forth between multiple tasks, operations, or mental sets" (p. 55); this function involves

adaptive changes in attentional control based on task demands.

3. Updating: "Updating and monitoring of working memory representations" (p. 56)

Friedman and Miyake (2004) extended the scope of the inhibition function. Using latent-variable analysis, they found that this function was used when resisting distractor interference as well as when inhibiting prepotent responses, suggesting that it involves maintaining task goals when confronted by environmental task-irrelevant stimuli or responses. The inhibition function is a general one involving executive control. This approach can be contrasted with other approaches identifying several different inhibition processes. For example, Nigg (2000) identified four types of effortful inhibition: interference control (interference due to resource or stimulus competition); cognitive inhibition (suppression of irrelevant information from working memory); behavioral inhibition (suppression of prepotent responses); and oculomotor inhibition (suppression of reflexive saccades). These inhibition processes may be conceptually separate, but Miyake et al. (2000) and Friedman and Miyake have found that at least three of these processes (interference control, behavioral inhibition, and oculomotor inhibition) seem to involve the same underlying inhibition function.

The evidence reviewed here suggests that the inhibition function involves using attentional control in a restraining way to prevent attentional resources being allocated to task-irrelevant stimuli and responses. As such, it is of direct relevance to attentional control theory. It remains to be determined whether the same inhibition function is involved in other forms of inhibition (e.g., inhibition of dominant conceptual pathways).

The shifting function is also of direct relevance to attentional control theory. It involves using attentional control in a positive way to shift the allocation of attention to remain focused on task-relevant stimuli. For example, a task in which two-digit numbers are presented and addition and subtraction are performed alternately involves shifting. Wager, Jonides, and Reading (2004) found in a meta-analysis that the same seven distinct brain areas were consistently activated across diverse shifting tasks, suggesting there is a single important shifting function.

The third central executive function identified by Miyake et al. (2000) is updating, which involves monitoring as well as updating. A representative task involving updating is one in which members of various categories are presented and participants keep track of the most recently presented member of each category. The updating function involves the transient storage of information rather than being directly concerned with attentional control. Accordingly, effects of anxiety on updating should be weaker than those on inhibition and shifting.

It is worth stressing that the brain areas most associated with the inhibition and shifting functions of the central executive are similar to those associated with the goal-directed attentional system (Miller & Cohen, 2001). Collette and Van der Linden (2002) reviewed brain-imaging studies focusing on the inhibition, shifting, and updating functions of the central executive and concluded that "some prefrontal areas (e.g., BA 9/46, 10 and anterior cingulate gyrus) are systematically activated by a large range of various executive tasks, suggesting their involvement in rather general executive processes" (p. 121).

In sum, the inhibition, shifting, and updating functions are partially separable. However, they are also partially interdependent in their functioning, suggesting they all rely to some extent on the resources of the central executive or top-down attentional system. Thus, demands on one function may reduce the processing resources of the central executive available for the other functions.

### *Attentional Control, Inhibition, and Shifting*

According to attentional control theory, anxiety impairs processing efficiency because it reduces attentional control (especially in the presence of threat-related distracting stimuli). As a result, the probability that processing resources will be diverted from task-relevant stimuli to task-irrelevant ones on tasks involving the inhibition and/or shifting functions is increased. In contrast, it was assumed within processing efficiency theory that anxiety impairs processing efficiency because anxiety produces worry. This reason for impaired processing efficiency is now subsumed within a broader conceptualization, according to which anxiety impairs the inhibition function. Anxious individuals are more distracted by task-irrelevant stimuli whether those stimuli are external (conventional distractors) or internal (e.g., worrying thoughts).

The inhibition function is impaired when task demands on the central executive are high. For example, Graydon and Eysenck (1989) used several tasks in which the demands on working memory differed by varying the processing and storage requirements. The adverse effects of distracting stimuli on task performance increased in line with task demands on working memory capacity. Lavie, Hirst, de Fockert, and Viding (2004) explored the same issue. Performance on a selective attention task was more adversely affected by distracting stimuli when overall demands on working memory were high. In addition, distraction effects on a task were greater when it involved the shifting function.

An alternative approach is to consider susceptibility to distraction as a function of individual differences in working memory capacity based on complex span measures (e.g., Daneman & Carpenter's [1980] reading span) assessing the ability to engage in concurrent processing and storage. Individuals low in working memory capacity were more susceptible to distraction than those high in working memory capacity (e.g., see Barrett, Tugade, & Engle, 2004, for a review). This approach demonstrates the usefulness of relating distraction effects to working memory capacity, but it has not been extended to be of direct relevance to an understanding of anxiety and susceptibility to distraction.

It is theoretically predicted that the functioning of the shifting function should also be impaired when task demands on the central executive are high. As yet, however, there is no evidence directly relevant to this prediction.

### *Summary*

In this section, we have presented the general theoretical framework. Its starting point is the crucial assumption of processing efficiency theory that anxiety impairs processing efficiency more than it does performance effectiveness. Of central importance to the revised theory is the notion that anxiety decreases the influence of the goal-directed attentional system and increases the influence of the stimulus-driven attentional system. This results in reduced



attentional control and impairment of the inhibition and shifting functions.

The theoretical framework provides the basis for several hypotheses, all of which have been investigated empirically. There are six main hypotheses associated with attentional control theory. Each hypothesis is discussed in the following section, along with the relevant findings. In the great majority of studies, participants were assigned to low- and high-anxious groups on the basis of their test or trait anxiety scores. Unless otherwise stated, this was the case with the experimental studies discussed below.

### Attention Control Theory: Hypotheses and Empirical Support

#### *Hypothesis 1: Anxiety Impairs Processing Efficiency to a Greater Extent Than Performance Effectiveness on Tasks Involving the Central Executive*

This hypothesis is based on the theoretical assumption that anxiety impairs two of the three key functions of the central executive (i.e., inhibition and shifting), thus producing processing inefficiency on the great majority of tasks involving the central executive. This processing inefficiency does not necessarily lead to decrements in performance effectiveness provided that anxious individuals respond to processing inefficiency by using compensatory strategies such as enhanced effort and use of processing resources.

Three kinds of evidence support Hypothesis 1 and are shortly discussed in turn. Most of the relevant findings were based on a theoretical framework in which the central executive was regarded as unitary. Thus, they are of only general relevance to attentional control theory, and their interpretation is somewhat equivocal. However, subsequent hypotheses are of direct relevance to attentional control theory.

*Time versus accuracy.* In most studies, accuracy is regarded as the primary measure of performance effectiveness. Within that context, the more time spent achieving a given level of performance, the lower the processing efficiency. Thus, response accuracy is typically a measure of performance effectiveness and response time efficiency. When low- and high-anxious individuals have comparable performance effectiveness, group differences in efficiency can be inferred from differences in response time. High anxiety was associated with comparable performance to low anxiety but with lengthened response time in several studies. This pattern was reported with verbal reasoning (Darke, 1988b, Experiments 2 and 3); spatial reasoning (Markham & Darke, 1991); grammatical reasoning (Derakshan & Eysenck, 1998; MacLeod & Donnellan, 1993); reading comprehension (Calvo & Carreiras, 1993; Calvo, Eysenck, Ramos, & Jiménez, 1994, Experiments 2, 3, and 4); verbal working memory (Ikeda, Iwanaga, & Seiwa, 1996); sustained attention (Elliman, Green, Rogers, & Finch, 1997); digit-string short-term memory (Derakshan & Eysenck, 1998; Richards, French, Keogh, & Carter, 2000); and course examinations (Benjamin, McKeachie, Lin, & Holinger, 1981).

*Effort and compensatory strategies.* One way in which high-anxious individuals can show impaired processing efficiency compared with low-anxious ones is by exerting greater effort but achieving only comparable performance. Effects of anxiety on effort can be assessed by self-report measures, psychophysiological

cal measures, and incentive manipulations. Each approach is considered in turn.

Dornic (1977) asked participants to estimate expended effort after task performance. Those who were neurotic introverts (high anxious) reported expending significantly more effort than those who were stable extraverts (low anxious) on complex versions of a closed-system thinking task. The two groups had comparable performance, so these findings suggest that anxiety reduces processing efficiency. Dornic (1980) found that anxiety was associated with increased mental effort on two versions of a complex task even though anxiety did not impair performance. N. C. Smith, Bellamy, Collins, and Newell (2001), using motor tasks, and Hadwin, Brogan, and Stevenson (2005), using cognitive tasks, also found higher effort ratings in high-anxious participants combined with no effects of anxiety on performance.

An alternative method of assessing effort expenditure involves psychophysiological measures. Cardiovascular measures are useful because they reflect motivation and task engagement (Schwerdtfeger & Kohlmann, 2004). The findings are nevertheless difficult to interpret. High-anxious groups exhibit greater cardiovascular reactivity than low-anxious ones in the pretask instruction phase and the posttask recovery phase (Calvo, Avero, & Jiménez, 1997; Calvo & Cano, 1997). However, there are typically no differences in cardiovascular indices of effort during task performance (Calvo, Szabo, & Capafons, 1996; Di Bartolo, Brown, & Barlow, 1997; Schönplflug, 1992), suggesting that high-anxious individuals do not increase effort expenditure more than low-anxious individuals.

A third approach involves the use of external incentives to manipulate motivation. Theoretically, high-anxious individuals typically use more processing resources than low-anxious ones in achieving a comparable level of performance. Thus, there is less scope for incentives to produce enhanced effort and performance in high-anxious groups. Calvo (1985) and Eysenck (1985) provided monetary incentives for good performance on a nonverbal inductive reasoning task or a letter-transformation task, respectively. In both studies, the performance of the high-anxious groups was generally unaffected by incentive, whereas that of the low-anxious groups was enhanced. Schönplflug (1992) obtained similar results.

In sum, self-report and incentive studies support the assumption that anxious individuals often compensate for impaired processing efficiency with additional effort. What compensatory strategies do they use? The answer depends on various factors (e.g., the precise task demands). The most systematic research was carried out on reading tasks by Calvo and colleagues (e.g., Calvo & Castillo, 1995; Calvo & Eysenck, 1996; Calvo et al., 1994; Calvo & Jiménez, 1996; Calvo, Ramos, & Eysenck, 1993). Two compensatory strategies frequently used by high-anxious individuals in evaluative stress conditions were reading regressions (i.e., looking back at previous text) and articulatory rehearsal (vocal and subvocal articulation during reading). It was assumed that regressions assist in the integration of prior with current text information, whereas articulatory rehearsal assists the phonological loop with the coding and short-term retention of words. Regressions were consistently the preferred strategy of high-anxious readers. Only if regressions were not possible (i.e., fixed-pace forward presentation of text) did high-anxious readers show increased vocal and subvocal articulation. Comprehension performance of high-anxious

individuals was comparable to that of low-anxious individuals when at least one compensatory strategy was available.

Theoretically, impaired attentional control is central to the reduced efficiency shown by high-anxious individuals. Accordingly, the most direct compensatory strategy would be to increase use of the shifting and/or inhibition functions to regain attentional control. Santos, Wall, and Eysenck (2006) used functional magnetic resonance imaging (fMRI) to assess brain activation while participants performed three tasks under no-switch and high-switch conditions. A comparison of brain activation in these two conditions (subtracting brain activation under no-switch conditions from that under high-switch conditions) indicated that high state anxiety was associated with significantly greater activation than low state anxiety in the right lateral prefrontal cortex (principally BA 9/46), an area associated with the shifting function (Collette & Van der Linden, 2002). Thus, anxiety produced inefficiency, and anxious individuals made increased use of the shifting function to compensate. These findings show the potential value of neuroimaging in assessing processing efficiency.

*Probe technique.* It follows from Hypothesis 1 that anxious individuals should devote more central executive processing resources to the performance of a main task and thus have fewer spare processing resources. This prediction can be tested by the probe technique. In essence, the instructions emphasize that the main task should be performed as well as possible. There is also a secondary task (responding rapidly to occasional auditory or visual probe signals). The more resources allocated to the main task, the fewer are available for the secondary task, and so probe reaction times will be slowed.

Hamilton (1978) used digit span as the primary task and interpolated probe stimuli between presentation of the digit string and its subsequent recall. In the most difficult condition (seven-digit string), high-anxious participants had significantly slower response latencies than low-anxious ones, implying they had less spare processing capacity. Eysenck (1989) used the probe technique, with the main task consisting of simple versions (one and two letters) of a letter-transformation task. The low- and high-anxious groups had comparable performance effectiveness on this task. However, they had significantly lower spare processing capacity than low-anxious individuals (and thus lower processing efficiency), as indicated by their significantly longer probe reaction times during the performance of two-letter problems.

Eysenck and Payne (2006) extended these findings. There were no effects of anxiety on performance effectiveness on the letter-transformation task. However, probe reaction time in high-anxious individuals was slowed under evaluative conditions compared with nonevaluative conditions, whereas the opposite pattern was found for low-anxious individuals. Under evaluative conditions, the slowing of high-anxious participants was directly related to the number of letters in the letter-transformation task.

The probe technique has also been used when the main task involves motor performance (simulated driving [Murray & Janelle, 2003]; table tennis [A. M. Williams, Vickers, & Rodrigues, 2002]). Murray and Janelle reported slower probe reaction times for high than for low trait-anxious participants, especially under competitive conditions. A. M. Williams et al. found that anxious participants had worse performance than nonanxious ones on the table-tennis task, as well as slower reaction times to probes. These findings suggest that anxiety reduced processing efficiency.

*Summary.* Research based on all three approaches indicates that anxiety impairs efficiency more than effectiveness. There is thus considerable support for one of the key assumptions of attentional control theory. The most direct evidence has come from studies using the probe technique (Eysenck, 1989; Eysenck & Payne, 2006; Hamilton, 1978; Murray & Janelle, 2003; A. M. Williams et al., 2002) and from use of fMRI (Santos et al., 2006). Future research should focus on replicating and extending the findings of Santos et al. because they assessed the effects of anxiety on processing efficiency and performance effectiveness on a relatively pure task involving the shifting function. Most of the existing research has used tasks involving various central executive functions, thereby making it difficult to provide an unequivocal interpretation of the findings.

### *Hypothesis 2: Adverse Effects of Anxiety on Performance Become Greater as Overall Task Demands on the Central Executive Increase*

According to attentional control theory, anxious individuals can compensate for the adverse effects of anxiety on processing efficiency of the inhibition and shifting functions by increased effort and use of resources. As a consequence, there may be small or nonexistent effects of anxiety on performance effectiveness. However, it becomes decreasingly possible for anxious individuals to compensate for impaired efficiency through increased effort and use of resources as overall task demands increase, and so decrements in performance become greater.

Two types of empirical research provide tests of Hypothesis 2. First, there is research in which only a single task is performed, with performance on different tasks varying in their demands on working memory (especially the central executive) being compared. Second, there is research using the loading paradigm, in which two tasks are performed concurrently. There is an invariant primary task performed concurrently with secondary tasks varying in their processing demands on the central executive.

All the studies reported manipulated the demands on the central executive. In the great majority of studies, this represented the major manipulation. However, the studies by Eysenck (1985) and by Ashcraft and Kirk (2001) manipulated demands on the phonological loop as well as on the central executive. These studies were based on a conceptualization in which the central executive was regarded as unitary. As such, most findings can be interpreted by processing efficiency theory (based on a unitary view of the central executive) and by attentional control theory (emphasizing its shifting and inhibition functions).

*Processing demands.* Much is known of the processing demands associated with reading, which makes it suitable for testing Hypothesis 2. For example, readers may draw anaphoric or elaborative inferences while reading. Anaphoric inferences are necessary for coherence and are drawn rapidly and automatically with minimal processing resources. In contrast, elaborative inferences take longer to construct, suggesting they require use of central executive resources. Darke (1988b) found that anxiety had no effect on verification speed of anaphoric inferences, but high-anxious individuals took longer than low-anxious ones to verify elaborative inferences. Richards et al. (2000) obtained convergent findings.

Text integration processes in reading involve connecting information held temporarily in memory across sentences and so increase demands on working memory capacity. Such demands are greater for integration processes than for individual-word lexical access. Calvo and Carreiras (1993) found an interaction between trait anxiety and psycholinguistic variables producing (or not producing) integration processes during reading. High-anxious participants were only more strongly affected than low-anxious ones by variables influencing text-level processes.

An alternative approach uses related tasks, with processing and storage demands being systematically manipulated. This approach is of direct relevance to working memory, a cognitive capacity involved in the transitory storage of the products of previous processes while subsequent information is being processed to integrate the previous and current information (Baddeley, 1986). Relevant research was reported by Eysenck (1985) and Ashcraft and Kirk (2001, Experiment 3), using a task involving transforming each letter of a one- to four-letter series mentally by counting forward (e.g., BH + 4 = ? [FL]). In both studies, high anxiety was related to impaired performance with increased demands, with the most detrimental effects of anxiety being obtained on four-letter tasks with a large transformation. Ashcraft and Kirk also reported similar findings with a number-transformation task.

In sum, there is consistent support for Hypothesis 2 that adverse effects of anxiety on performance are greater on tasks imposing considerable demands on central executive processes and/or the working memory system as a whole.

*Loading paradigm.* In the loading paradigm, the same main or primary task is performed concurrently with a secondary task or load imposing low or high demands on the central executive. Adverse effects of anxiety on main-task performance should be greater when the secondary or load task imposes high demands on the central executive (especially the inhibition and shifting functions).

There are two differences between the precise predictions of processing efficiency theory and attentional control theory with the loading paradigm. First, attentional control theory emphasizes demands on the inhibition and shifting functions rather than general demands on the central executive. Second, the emphasis in processing efficiency theory was on the demands of the two tasks considered separately. In contrast, attentional control theory emphasizes the demands on attentional control. Performing two tasks concurrently typically requires attentional control (especially the shifting function) to coordinate processing on the two tasks in addition to the demands of each task separately. Accordingly, anxiety should impair performance on the primary task even if the secondary task does not require central executive processes, provided attentional control is needed to coordinate performance. In contrast, processing efficiency theory predicts no impairment of performance in these circumstances.

The loading paradigm was used by MacLeod and Donnellan (1993). A verbal reasoning task formed the primary task; the secondary task involved low or high memory load. No effect of anxiety was observed on the concurrent memory task. As predicted by Hypothesis 2, the adverse effects of the more demanding secondary task on verbal reasoning performance were significantly greater in high trait-anxious individuals. Derakshan and Eysenck (1998) successfully replicated MacLeod and Donnellan's key findings. From the perspective of attentional control theory, it is

important that the low load condition in these two studies did not require use of the shifting function to coordinate processing on the two concurrent tasks.

Ashcraft and Kirk (2001, Experiment 2) used the loading paradigm when the primary task consisted of addition problems and the secondary or load task involved remembering two or six randomly selected consonants. Adverse effects of math anxiety emerged in math performance only with a six-letter memory load. Calvo and Ramos (1989) reported similar findings with motor tasks.

There are two limitations with these studies. First, they do not directly address the issue of which working memory components are most affected by anxiety. Second, it is assumed theoretically that anxiety affects the modality-free functions of the central executive. However, the primary and secondary tasks used by MacLeod and Donnellan (1993) and by Derakshan and Eysenck (1998) were both verbal. Thus, the key findings could be re-expressed as showing that anxiety impairs the ability to perform two demanding verbal tasks concurrently.

Eysenck, Payne, and Derakshan (2005) addressed these issues. Participants low and high in trait anxiety performed a complex visuospatial task concurrently with various secondary tasks. As predicted, anxiety had an adverse effect on main-task performance when the secondary task required use of central executive processes. Also as predicted, anxiety did not impair main-task performance when the secondary task involved the phonological loop or the visuospatial sketchpad.

In sum, anxiety reduces available central executive capacity. However, although the loading paradigm has proved useful in identifying the working memory component most adversely affected by anxiety, it has as yet failed to shed light on the central executive functions most involved. It remains for future research to clarify this issue. It has often been assumed that dual-task performance (including performance using the loading paradigm) reflects rapid task switching (e.g., Duncan, 1995). In that case, the finding that anxiety lowers performance when two attentionally demanding tasks are performed concurrently may be due to impaired attentional control in anxiety. However, in the absence of direct manipulation of demands on attentional control, the interpretation is equivocal.

### *Hypothesis 3: Anxiety Impairs Attentional Control by Increasing the Influence of the Stimulus-Driven Attentional System*

The research discussed in this section focuses on general aspects of attentional control and the ways in which anxiety affects the stimulus-driven attentional system. According to attentional control theory, anxiety changes the balance between the goal-directed and the stimulus-driven attentional systems, increasing the impact of the latter system. More detailed findings concerning the effects of anxiety on components of attentional control are discussed in connection with Hypotheses 4 and 5.

*Attentional control: Questionnaire studies.* The relationship between anxiety and attentional control has been assessed in several questionnaire studies. Such evidence is of relevance to attentional control theory. However, humans have only a limited ability to introspect about their own attentional control, and so questionnaire studies need to be supported by experimental data.

All the main questionnaires assessing attentional control have treated it as a traitlike construct. Broadbent, Cooper, FitzGerald, and Parkes (1982) devised the Cognitive Failures Questionnaire to assess individual differences in minor everyday slips or errors mostly reflecting inadequate attentional control. Sample items are as follows: "Do you fail to notice signposts on the road?" and "Do you start doing something at home and get distracted into doing something else (unintentionally)?" Broadbent et al. claimed some validity for the Cognitive Failures Questionnaire by finding that self-report scores correlated moderately with ratings by others. They found that scores on the Cognitive Failures Questionnaire correlated .31 with trait anxiety. Friedman and Miyake (2004) used latent-variable analysis applied to the data from several tasks to identify an inhibition function. Scores on the Cognitive Failures Questionnaire correlated significantly with this inhibition function.

More direct evidence has been reported in studies using the Attentional Control Scale (see Derryberry & Reed, 2002), which assesses attentional focusing and attentional shifting between tasks. Derryberry and Reed reported a correlation of  $-.42$  between trait anxiety and attentional control using this scale, and they referred to a correlation of  $-.55$  between those two variables in an unpublished study of theirs.

*Attentional control: Dual-task paradigm.* In the typical dual-task paradigm used in anxiety research, a primary task is presented in the center of the visual field and a concurrent secondary task is presented in the periphery. According to attentional control theory, anxiety makes it difficult for the goal-directed attentional system to override the stimulus-driven attentional system. Thus, anxious individuals should generally attend to salient or conspicuous stimuli because such stimuli command attention from the stimulus-driven attentional system (Corbetta & Shulman, 2002). If the primary task stimuli are more salient than secondary task stimuli, anxiety should impair secondary task performance more than primary task performance. However, if the primary task stimuli are no more salient (or less salient) than the secondary task ones, then anxiety should not impair performance on the secondary task. The reason is that attentional processes in anxious individuals are more influenced by the stimulus-driven attentional system than those in nonanxious individuals.

The predictions of attentional control theory can be compared with those of Easterbrook's (1959) hypothesis, still considered the dominant theoretical position (e.g., Staal, 2004). According to Easterbrook's hypothesis, anxiety narrows attention, creating a tunnel effect, with this attentional narrowing reflecting a relatively passive and automatic physiological process. As anxiety increases, attentional narrowing produces enhanced focusing on those task stimuli emphasized by the instructions, combined with decreased attention to all other stimuli. There is no mention of stimulus salience in Easterbrook's theoretical approach. The key prediction from his approach is that the attentional narrowing produced by anxiety focuses attention on primary task stimuli and so impairs performance of the secondary task more than that of the primary task.

There have been various reviews (e.g., Eysenck, 1982; Staal, 2004), and so the focus here is on key findings. Attentional control theory and Easterbrook's (1959) hypothesis both predict that anxiety will produce impaired performance on the secondary task

when the primary task is cognitively demanding and secondary task stimuli are less salient than primary task ones. Most findings are consistent with this prediction (e.g., Janelle, Singer, & Williams, 1999; Murray & Janelle, 2003; Wachtel, 1968; Weltman, Smith, & Egstrom, 1971; J. M. Williams, Tonyon, & Andersen, 1990, 1991). In these studies, the primary task stimuli were more salient than the secondary task ones: The primary task was presented in the center of the visual field and required continuous performance, whereas secondary task stimuli were presented infrequently and in the periphery. In all these studies, anxiety was associated with impaired performance on the secondary task.

Easterbrook's (1959) hypothesis and attentional control theory lead to different predictions when the secondary or peripheral stimuli are at least as salient as those of the primary task. Easterbrook's hypothesis continues to predict that anxiety should impair secondary task performance. In contrast, attentional control theory predicts that anxiety should not impair secondary task performance because the stimulus-driven attentional system has more influence on anxious than on nonanxious individuals, and this reduces the attentional focus on the primary task emphasized in the instructions. There are six relevant studies (Dusek, Kermis, & Mergler, 1975; Dusek, Mergler, & Kermis, 1976; Markowitz, 1969; Shapiro & Johnson, 1987; Shapiro & Lim, 1989; Solso, Johnson, & Schatz, 1968), all discussed in the following paragraphs.

In the studies by Dusek et al. (1975, 1976), the secondary task stimuli (drawings of household objects) were comparable in salience to the primary task stimuli (drawings of animals) and were presented together. In both studies, participants high in test anxiety had significantly better recall of the secondary task stimuli than those low in test anxiety, with the opposite being the case for recall of the primary task stimuli.

Markowitz's (1969) primary task involved intentional learning of meaningless trigrams, whereas his secondary task involved incidental learning of words. The secondary task stimuli were salient in that they were more meaningful than the primary task stimuli and were presented immediately above those on the primary task. Participants high in trait anxiety performed significantly better on the secondary task under high-stress than low-stress conditions.

In the studies by Shapiro and Johnson (1987) and Shapiro and Lim (1989), a stressful condition was created by presenting electric shocks or by presenting anxiety-creating music. When central and peripheral stimuli of equal salience were presented concurrently, the anxious participants in both studies were much less likely than the nonanxious ones to perceive the central stimulus first.

Solso et al. (1968) presented seven items briefly for subsequent recall at varying distances from the fixation point. Recall of the items presented furthest from the fixation point was highly significantly greater for the high-anxious participants than for the low-anxious ones, but anxiety did not affect recall of items presented close to the fixation point.

In conclusion, attentional control theory is more consistent with the findings than is Easterbrook's (1959) hypothesis. The main reason is that the salience of secondary task stimuli (emphasized within attentional control theory but ignored within Easterbrook's hypothesis) crucially influences effects of anxiety on secondary task performance. In addition, attentional control theory is closely



related to a major theoretical approach to attention (exemplified by Corbetta & Shulman, 2002; Posner & Petersen, 1990).

*Stimulus-driven attentional system: Performance enhancement.* According to Hypothesis 3, anxiety increases the influence of the stimulus-driven attentional system relative to the goal-directed attentional system. Thus, performance on tasks in which the stimulus-driven attentional system is sufficient for performance is likely to be enhanced by anxiety. Anxiety produces preferential attention to threat-related stimuli (and to slow disengagement), and so beneficial effects of anxiety on performance are especially likely when the task involves responding to threat-related stimuli. Relevant research involving neutral stimuli is discussed first, followed by studies involving threat-related stimuli. Neutral stimuli are defined as those lacking emotional content. It is, of course, possible that neutral stimuli may produce anxiety in participants who perceive them as interfering with performance or as signaling a difficult task (e.g., those high in math anxiety confronted by a problem in math (Ashcraft & Kirk, 2001).

The effects of anxiety on paired-associate learning were studied in the 1950s and 1960s (Spence, Farber, & McFann, 1956; Spence, Taylor, & Ketchel, 1956; Standish & Champion, 1960). In these studies, there were lists consisting of competition and noncompetition paired associates. Before list formation, pairs of items in which the response item was the strongest associate of the stimulus item were selected. The competition lists involved re-associating the stimulus and response items so the strongest associate of the stimulus item was associated with a different stimulus word. In contrast, the noncompetition lists simply consisted of the original stimulus-response pairings.

According to attentional control theory, the stimulus-driven attentional system should produce the correct responses on the noncompetition lists, and so anxiety should enhance performance. In contrast, use of the stimulus-driven attentional system (combined with anxiety-related impairment in the inhibition of strong associates) would produce incorrect responses on competition lists, and so anxiety should impair performance. This pattern was found in all three studies (Spence, Farber, & McFann, 1956; Spence, Taylor, & Ketchel, 1956; Standish & Champion, 1956). Thus, anxiety can enhance performance when the required responses primarily require use of the stimulus-driven attentional system.

Several studies have assessed effects of anxiety on performance with threat-related stimuli (defined by their content). For example, Byrne and Eysenck (1995) used a task involving detection of angry faces in neutral crowds. The detection speed of a high-anxious group was significantly greater than that of a low-anxious group. Fox and Georgiou (2005) reviewed the findings from several experiments on detection of threat-related stimuli. Overall, there was a small reduction in detection time in participants high in trait anxiety.

Evidence supporting Hypothesis 3 has come from studies of attentional bias (see Eysenck, 1992, for a review). Attentional bias is the tendency to attend to threat-related stimuli (or more often to show slow attentional disengagement from such stimuli) when presented concurrently with neutral stimuli. It is generally assessed by the dot-probe task on which participants respond rapidly when a dot is detected. When a threat-related stimulus and a neutral stimulus are presented concurrently, anxious individuals typically respond faster than nonanxious ones to the dot when it replaces the

threat-related stimulus but respond slower when it replaces the neutral stimulus (e.g., Eysenck, MacLeod, & Mathews, 1987; Mogg et al., 2000; Pishyar, Harris, & Menzies, 2004; see Eysenck, 1997, 2004, for reviews). Fox et al. (2002) showed that the attentional bias associated with anxiety depends mainly on the difficulty anxious individuals have in disengaging from threat-related stimuli.

Findings on attentional bias support two assumptions of attentional control theory. First, the stimulus-driven attentional system in anxious individuals is more affected by threat-related stimuli than in nonanxious individuals. Second, and following from the first assumption, anxiety produces enhanced performance under the conditions predicted by the theory (i.e., when the task stimuli themselves are threat related).

#### *Hypothesis 4: Anxiety Impairs Efficiency (and Often Effectiveness) on Tasks Involving the Inhibition Function, Especially With Threat-Related Distractors*

According to Friedman and Miyake (2004), the inhibition function consists of two highly intercorrelated components: prepotent response inhibition and resistance to distractor interference. According to attentional control theory, anxiety reduces the efficiency of inhibition in the sense of reducing inhibitory control on incorrect prepotent or dominant responses and on attention to task-irrelevant stimuli. These adverse effects are greater with threat-related than with neutral distracting stimuli because the bottom-up attentional system in anxious individuals is especially responsive to threat-related stimuli. Negative effects of anxiety on performance should be greater when overall processing demands are high and anxious individuals have insufficient processing capacity to regain attentional control.

According to attentional control theory, the adverse effects of anxiety on the inhibition function mean that anxious individuals are more distracted than nonanxious ones by external task-irrelevant stimuli presented by the experimenter and by internal task-irrelevant stimuli (e.g., worrying thoughts; self-preoccupation). There are very few studies in which the number of worrying thoughts has been manipulated systematically, and so we focus on the effects of external task-irrelevant stimuli.

*Prepotent response inhibition.* Early studies on the effects of anxiety on prepotent response inhibition were reported in Spence, Farber, and McFann (1956); Spence, Taylor, and Ketchel (1956); and Standish and Champion (1960), already discussed. In these studies, participants low and high in trait anxiety learned lists of paired associates. In the relevant condition (competition lists), the stimulus and response words were re-paired so that the strongest associate of each stimulus word was associated with a different stimulus word. Anxiety significantly impaired the paired-associate learning on these competition lists because anxious individuals had difficulty inhibiting the prepotent (but incorrect) responses (this could also involve conceptual inhibition).

Pallak, Pittman, Heller, and Munson (1975) used the Stroop task with low- and high-anxious individuals. Anxiety adversely affected performance speed only in the condition requiring inhibition of prepotent responses (i.e., color naming of other color words). Hochman (1967, 1969) also used the Stroop task. In both studies, individuals in the high-stress condition performed significantly

worse than did the participants in the low-stress condition when the color name and the color word conflicted.

*Resistance to distractor interference.* The effects of anxiety on resistance to distraction have been assessed using various paradigms. It is assumed that the adverse effects of anxiety on ability to resist distraction are mediated by attentional processes. It is thus predicted that anxious individuals will attend to distracting stimuli more than will nonanxious individuals.

Effects of anxiety on susceptibility to distraction as assessed by eye movements away from the current task have been reported. Nottelman and Hill (1977) found children high in test anxiety glanced more often than those low in test anxiety at a distracting task. Alting and Markham (1993) found in an evaluative condition that individuals high in test anxiety spent longer than those low in test anxiety in off-task glancing only when a distractor was present. Janelle et al. (1999) used simulated car driving as their central task. When distracting stimuli were presented to the periphery, anxious participants had far more eye movements toward peripheral locations than did nonanxious participants.

Dornic and Fernaeus (1981) compared neurotic introverted (high trait-anxious) and stable extraverted (low trait-anxious) individuals on three tasks. Distraction effects on main-task performance were significantly greater on each task for those who were neurotic introverts. Hopko et al. (1998) studied the effects of distraction (i.e., distracting phrases) on a reading task. The reading speed of individuals high in math anxiety was more adversely affected by the distracting phrases than that of individuals low in math anxiety.

The effects of distraction were investigated by Eysenck and Graydon (1989) and Calvo and Eysenck (1996). Eysenck and Graydon found the performance of neurotic introverted (high trait-anxious) individuals on a letter-transformation task was more impaired by distracting stimuli resembling task stimuli than was the performance of stable extraverted (low trait-anxious) individuals. However, Keogh and French (1997) failed to replicate their key findings.

Calvo and Eysenck (1996) investigated effects of distraction (meaningful speech) on text comprehension. The text was presented to minimize or maximize memory demands on working memory. Distraction had a significantly greater negative effect on the text comprehension performance of the high-anxious group than of the low-anxious group only when the comprehension task was highly demanding. The findings of Calvo and Eysenck in conjunction with those of Calvo and Castillo (1995) indicate that the greater susceptibility to distraction on a comprehension task of high-anxious individuals depends mainly on phonological interference.

Wood, Mathews, and Dalgleish (2001) had participants decide whether a probe word was related to the meaning of a preceding sentence. In one condition, a homograph was presented in the sentence, and the probe word was related to a meaning of the homograph inappropriate within the sentence context (e.g., *Ace* following "He dug with a spade"). This task was performed on its own or concurrently with a demanding task (remembering strings of random digits). Individuals high in trait anxiety showed impaired inhibitory processing of irrelevant meanings of homographs relative to those low in trait anxiety (in terms of errors and latencies) only when there was a concurrent demanding task. Thus, individuals high in trait anxiety were less able to limit processing

of task-irrelevant or distracting information in conditions of high overall task demands.

*Inhibition: Threat-related stimuli versus neutral stimuli.* The adverse effects of anxiety on task performance caused by task-irrelevant stimuli are greater when they are threat related rather than neutral. Much of the relevant research has involved the emotional Stroop task (see Williams, Mathews, & MacLeod, 1996, for a review). On this task, neutral or threat-related words are presented in color, and participants name the color as rapidly as possible. The prediction is that the effects of anxiety in slowing color-naming performance should be greater when the words are threat related; this is the emotional Stroop interference effect. Note that inhibition of color processing/naming is task relevant, and therefore slowed responses imply that there is insufficient inhibition.

Mogg, Mathews, Bird, and MacGregor-Morris (1990) found that trait anxiety was positively associated with the magnitude of the emotional Stroop interference effect. Richards and French (1990) found with the emotional Stroop task that individuals high in trait anxiety had significantly longer naming latencies for anxiety-related words than for neutral words. There was no effect of anxiety on response times to happiness-related words, so the effects of anxiety centered on anxiety-related words rather than simply on emotional words. Mogg and Marden (1990) found that high trait-anxious participants were slower than low trait-anxious ones in color naming threat-related and emotionally positive words, suggesting that anxiety influences processing of all emotional words. Martin, Williams, and Clark (1991) found no effect of trait anxiety on color naming of threat-related words. Egloff and Hock (2001) reported that the emotional Stroop interference effect was determined interactively by trait anxiety and state anxiety, with the greatest interference effect being shown by individuals high in both trait and state anxiety.

Several researchers have studied the emotional Stroop task under subliminal and supraliminal conditions. Mogg, Bradley, Williams, and Mathews (1993) found a slowing of performance in individuals high in trait anxiety only when threat-related stimuli were presented subliminally. In contrast, van den Hout, Tenney, Huygens, Merckelbach, and Kindt (1995) found that high state and trait anxiety were associated with slowed color naming of threat-related words in both subliminal and supraliminal conditions. MacLeod and Hagan (1992) found in a stressful condition that trait and state anxiety were both associated with slowed color naming of threat-related words only with subliminal presentation.

MacLeod and Rutherford (1992) compared performance on the emotional Stroop task under nonstressful and stressful conditions. Under subliminal conditions, however, individuals high in trait anxiety showed an interference effect with threat-related stimuli only in the stressful condition.

There are other studies in which effects of neutral and threat-related distractors on performance were compared. Eysenck and Byrne (1992) assessed performance on a reaction time task involving target-word detection in the presence of social-threat, physical-threat, positive, and neutral words. Greater susceptibility to distraction among individuals high in trait anxiety than among those low in trait anxiety was found only with physical threat distractors.

Byrne and Eysenck (1995) considered speed of detection of a happy face in the context of neutral faces or angry faces. Individuals high in trait anxiety took longer to detect happy faces when

the nontarget faces were angry rather than neutral, whereas distractor type had no effect on performance among low-anxious individuals.

Keogh and French (2001) and Keogh, Bond, French, Richards, and Davis (2004) studied distraction effects on a reaction time task involving focused attention or selective search. With focused attention in evaluative conditions, the performance of individuals high in test anxiety was more adversely affected by threat-related distractors than was that of those low in test anxiety. Keogh et al. reported that the performance of individuals high in test anxiety was more adversely affected by threat-related than by nonthreat distractors, whereas individuals low in test anxiety were comparably affected by threat-related and nonthreat distractors. Contrary to prediction, however, these findings occurred mainly because individuals high in test anxiety were less affected by nonthreat distractors.

The spatial cueing paradigm is also of relevance to distraction effects in anxiety. Participants are presented with valid cues (identifying the location at which the target will be presented) or invalid cues (providing misleading information). The cue can be regarded as a distracting stimulus on invalid trials, and effective attentional control would involve rapid disengagement from invalid cues. Anxious individuals found it harder than nonanxious ones to disengage from invalid cues (Poy, Eixarch, & Ávila, 2004). Using a similar paradigm, Fox et al. (2002) and Yiend and Mathews (2001) found anxious participants took longer than nonanxious ones to disengage only from invalid threat-related stimuli. Thus, the findings agree with those using other paradigms.

Neurophysiological evidence was reported by Bishop, Duncan, Brett, and Lawrence (2004). In the experimental condition (in which many threat-related distracting stimuli were presented), Bishop et al. argued that participants would need increased attentional control to minimize the disruptive effects of the distractors. Participants high in state anxiety showed decreased activation of the lateral prefrontal cortex (associated with attentional control) in the experimental condition compared with a control condition involving few threat-related distractors, whereas those low in state anxiety showed increased activation. Bishop et al. concluded that "anxiety is associated with reduced top-down control over threat-related distractors" (p. 184).

*Summary.* According to the theory, anxiety should consistently impair the inhibition function and thus generally impair performance. This prediction has been supported. Anxiety had a significantly adverse effect on the performance of tasks assessing inhibition in 31 comparisons. Theoretically, the greater susceptibility to distraction shown by anxious individuals should be especially great when task demands are high. This prediction has been supported in several studies (e.g., Calvo & Eysenck, 1996; Eysenck & Graydon, 1989; Wood et al., 2001).

The impaired efficiency of the inhibition function shown by anxious individuals compared with nonanxious ones should reduce performance effectiveness more when task-irrelevant stimuli are threat related rather than neutral. This should occur because anxious individuals are more responsive to threat-related distractors in a relatively automatic fashion via the stimulus-driven attentional system. The former prediction has received support in several studies (e.g., Egloff & Hock, 2001; Eysenck & Byrne, 1992; Keogh & French, 2001; MacLeod & Rutherford, 1992; Mogg et al., 2000, 1990; Mogg & Marden, 1990; Richards & French,

1990). The latter prediction would receive support if anxiety were associated with interference on the emotional Stroop task when threat-related stimuli are presented subliminally. Confirmatory findings have been reported in several studies (e.g., MacLeod & Hagan, 1992; MacLeod & Rutherford, 1992; Mogg et al., 1993; van den Hout et al., 1995). What awaits further research is to investigate whether the adverse effects of anxiety on the inhibition function are greater with respect to processing efficiency than to performance effectiveness.

All the studies considered in this section involved external distracting stimuli. However, the same theoretical assumptions can be used to explain why internal distracting stimuli (especially threat-related ones such as worrying thoughts) attract attention away from the task and impair performance.

#### *Hypothesis 5: Anxiety Impairs Processing Efficiency (and Often Performance Effectiveness) on Tasks Involving the Shifting Function*

Miyake et al. (2000) identified switching as a basic control process or central executive function. They found that switching was assessed most validly in dual-task conditions in which there was experimenter-determined switching between tasks (e.g., alternating between addition and subtraction problems). Task switching involves the performance of two tasks in rapid succession. It is associated with costs (e.g., increased reaction times and/or errors) immediately after the switch, as compared with a control condition in which the same tasks are used but there is little or no switching between tasks (see Monsell, 2003, for a review). These switching costs are incurred in part because of the need to exert attentional control when one task is replaced by a second one (e.g., Monsell & Driver, 2000; Rogers & Monsell, 1995). On the assumption that the requirement to exert attentional control plays an important role in determining switching costs, anxiety should impair efficiency when task switching is necessary and will often impair performance.

The shifting function is also often used in prospective memory studies, which generally involve two tasks. The primary task is performed almost continuously, and a concurrent prospective memory task is performed sporadically in response to some cue (e.g., auditory or visual signal). Failures on the prospective memory task occur when participants do not shift attention to that task when cued.

*Task switching.* Miyake et al. (2000) found that the Wisconsin Card Sorting Task (which involves shifting sorting categories) primarily involves the shifting function of the central executive. Goodwin and Sher (1992) found that high-anxious individuals made more errors and took longer to complete this task than did low-anxious individuals.

Santos and Eysenck (2006) used a task-switching paradigm resembling that used by Gopher, Armony, and Greenspan (2000). A digit was presented on each trial, and there were three different tasks (odd vs. even; 1–4 vs. 6–9; or first letter A–R vs. S–Z) signaled by the location of the digit on a computer screen (top third, middle, or bottom third, respectively). Anxious participants were significantly slower than nonanxious participants on the first postswitch trial.

Santos et al. (2006) carried out a more thorough investigation of the effects of anxiety on task-switching performance using the

same three tasks. In this study, there was no effect of state anxiety on performance. However, anxiety affected task-switching efficiency. Of particular significance was the finding of additional brain activation in the high-switch condition than in the no-switch one in anxious rather than nonanxious individuals in brain areas associated with central executive functioning (right BA 9/46). This is an area closely resembling the one found by Bishop et al. (2004) to be associated with effects of anxiety on attention. This additional brain activation was significantly greater in high-anxious than in low-anxious participants. The finding that impaired processing efficiency in high anxiety occurred when task switching and high levels of attentional control were required supports attentional control theory. The finding that brain areas associated with central executive functioning generally and shifting in particular were more activated in high anxiety than in low anxiety provides additional support for the theory.

*Prospective memory.* Prospective memory tasks involve “identifying or recognizing cues as telltale signs of previously formed plans and intentions when they (the cues) occur as part of ongoing thoughts, actions, or situations” (Graf & Uttl, 2001, p. 442). As indicated previously, errors on prospective memory tasks reflect failures of attentional shifting. The cues signaling a task switch are low in salience, and high levels of performance (i.e., few errors) require an effective goal-directed plan. Thus, the adverse effects of anxiety on the goal-directed attentional system mean it should typically impair prospective memory performance.

Cockburn and Smith (1994) assessed prospective memory by instructing participants to respond to hearing a timer by asking when they would see the experimenter again. There was a considerable delay between hearing those instructions and actually hearing the timer. Highly anxious participants had significantly more failures of prospective memory than did less anxious ones.

Harris and Menzies (1999) used a demanding primary task (generating semantic associates to 60 spoken words and remembering the spoken words) in conjunction with a prospective memory task (placing an *x* beside items belonging to the categories of clothing or body parts). Performance on the prospective memory task was significantly negatively correlated with state anxiety.

Similar findings were reported by Harris and Cumming (2003). Participants performed closely matched retrospective and prospective memory tasks, and the prospective memory task was carried out concurrently with a very demanding primary task. Individuals high in state anxiety performed significantly worse than those low in state anxiety on the prospective memory task.

In sum, anxiety reliably impairs performance on prospective memory tasks (Cockburn & Smith, 1994; Harris & Cumming, 2003; Harris & Menzies, 1999). There is also suggestive evidence (Santos & Eysenck, 2006) that anxiety impairs task-switching performance on a task not involving prospective memory. As yet, the focus has been only on the main effect of anxiety. However, various predictions can be made from attentional control theory, based on the assumption that anxiety impairs the functioning of the goal-directed attentional system. The adverse effects of anxiety on prospective memory should be reduced or eliminated if it is made easier for anxious individuals to maintain an effective goal-directed plan (and thus attentional control) up until the time when prospective memory is tested. This could be done by making the cues for prospective memory more salient or conspicuous or by

shortening the time between the formation of the goal-directed plan and the testing of prospective memory.

*Hypothesis 6: Anxiety Impairs Processing Efficiency (and Sometimes Performance Effectiveness) on Tasks Involving the Updating Function Only Under Stressful Conditions*

The third function of the central executive identified by Miyake et al. (2000) is updating. According to attentional control theory, updating does not directly involve attentional control, and so anxiety does not impair the updating function under nonstressful conditions. Under stressful conditions, however, the overall demands on the central executive are increased. As a consequence, there is a reduction in processing efficiency, which may produce impaired performance on updating tasks.

Two tasks assessing updating are reading span and operation span (discussed below). Miyake et al. (2000) found that the operation-span task primarily involves updating, and the reading-span task involves very similar processes (see Daneman & Merikle, 1996).

Reading span is assessed by requiring participants to read a series of sentences for comprehension followed by recall of the last word in each sentence (Daneman & Carpenter, 1980). Reading span is defined as the maximum number of sentences for which all the last words can be recalled. In similar fashion, operation span involves presenting arithmetical problems, each followed by a word, and operation span is defined as the maximum number of items for which participants can remember all the last words (Turner & Engle, 1989).

Reading-span and operation-span tasks differ from tasks used to assess inhibition and switching in three main ways. First, span tasks (and other tasks assessing updating) focus on memory rather than ongoing processing. Second, and related to the first point, the main dependent variable is a measure of memory capacity. According to Cowan et al. (2005), span measures such as reading and operation span provide relatively pure measures of memory capacity because task demands prevent rehearsal and grouping processes.

Third, and most important, tasks used to assess reading and operation span impose few demands on attentional control. This is suggested by the pattern of findings across central executive functions reported by Miyake et al. (2000) and subsequently supported by Duff and Logie (2001) in a study on operation span. Suppose that attentional control is required to coordinate the processing of the two component tasks involved in operation span, namely, arithmetic verification and memory span. If so, then performance of the component tasks should be substantially impaired under dual-task compared with single-task conditions. In fact, there were very small impairment effects on each task when performed concurrently, indicating that operation span depends relatively little on attentional control. Similar findings were reported by Bunge, Klingberg, Jacobsen, and Gabrieli (2000). It might be argued that reading and operation span involve inhibition (e.g., of information on the primary task that is irrelevant to the memory task) and that reading span involves meaning-related inhibition. However, Friedman and Miyake (2004) found there was a small negative correlation between performance on reading span and the inhibition function based on latent-variable analyses.



The effects of situational stress on reading span have been assessed in several studies. Darke (1988a) used a stressful situation (i.e., ego-threat instructions) and found reading span was significantly lower in high test-anxious participants than in low test-anxious ones. Sorg and Whitney (1992) assessed reading span under nonstressful and stressful (i.e., videogame competition) conditions. High trait-anxious participants performed better than those low in trait anxiety under nonstressful conditions. Under stressful conditions, only the performance of the high-anxious group decreased. In a similar study, Santos and Eysenck (2005) investigated operation span under nonstressful (control) and stressful (i.e., close observation by experimenter; failure feedback) conditions. There were no differences in span performance between groups low and high in trait anxiety.

Calvo and colleagues carried out three studies to assess the effects of test anxiety on reading span (Calvo & Eysenck, 1996; Calvo et al., 1994; Calvo, Ramos, & Estevez, 1992). In all three studies, there were nonsignificant effects of test anxiety on reading span under nonstressful conditions. In the only study including a stressful condition (Calvo et al., 1992), those high in test anxiety had lower reading span than those low in test anxiety.

Dutke and Stöber (2001) used an updating task in which participants updated the number of occurrences of each of three target numbers, responding when any target had been presented three times. There were two conditions varying in the number of targets presented. In the first experiment, the main effect of anxiety was nonsignificant. However, high-anxious participants performed better than low-anxious ones when many targets were presented but worse when few targets were presented. In the second experiment, there was again no main effect of anxiety, and the high- and low-anxious groups did not differ in either condition.

In sum, there are no effects of anxiety on the updating function assessed by reading or operation span when the conditions are nonstressful (Calvo & Eysenck, 1996; Calvo et al., 1994, 1992; Santos & Eysenck, 2005). With a different updating task, Dutke and Stöber (2001) found no overall effect of anxiety on performance in two experiments. When stressful conditions are used, the findings are inconsistent and difficult to interpret. Darke (1988a) and Calvo et al. (1992) found that high test anxiety was associated with impaired reading span under those conditions, Sorg and Whitney (1992) did not find clear differences between high- and low-test anxious individuals in stressful conditions, and Santos and Eysenck found no difference between individuals high and low in trait anxiety.

### Summary and Conclusions

An important commonality between attentional control theory and processing efficiency theory is the assumption that the effects of anxiety on cognitive processing center on the central executive component of Baddeley's (1986, 2001) working memory system. Much evidence (e.g., Derakshan & Eysenck, 1998; MacLeod & Donnellan, 1993) supports that assumption, with the clearest evidence having been reported by Eysenck et al. (2005).

The advantages of attentional control theory over processing efficiency theory can be identified by reconsidering the four limitations of processing efficiency theory stated earlier. First, it was unclear within processing efficiency theory which functions of the central executive are most affected by anxiety. In contrast, atten-

tional control theory identifies the basic central executive functions (i.e., shifting and inhibition) most affected by anxiety. The impaired functioning of these functions associated with attentional control increases the influence of the stimulus-driven attentional system.

Second, it was simply assumed in processing efficiency theory that worry in anxious individuals reduces their processing efficiency. In attentional control theory, it is explained by the combination of impaired attentional control and preferential processing of threat-related stimuli. More generally, attentional control theory accounts for distraction effects in anxiety, and the distracting stimuli can be either *external* (as in most research) or *internal* (e.g., worry).

Third, processing efficiency theory was not concerned with distraction effects, whereas such effects are regarded as important within attentional control theory. According to attentional control theory, anxiety impairs the inhibition function. The increased distractibility found in anxious individuals compared with nonanxious ones provides strong support for that assumption.

Fourth, no predictions were made within processing efficiency theory concerning possible interactions between anxiety and type of stimulus (threat related vs. neutral). The effects of anxiety on attentional processes and performance depend on whether the stimuli presented are neutral or threat related (e.g., attentional bias). In contrast, attentional control theory predicts that adverse effects of anxiety on performance will be greater when task-irrelevant stimuli are threat related than when they are neutral, a prediction that has been confirmed several times. According to the theory, this prediction arises because the inhibitory function in anxious individuals is especially inefficient in the presence of threat-related distractors.

Attentional control theory makes various predictions about effects of anxiety on susceptibility to distraction, dual-task performance, and task-switching performance. There is broad support for the notion that anxiety disrupts the functioning of the goal-directed attentional system, producing several effects including the following: (a) reduced ability to inhibit incorrect prepotent responses, (b) increased susceptibility to distraction, (c) impaired performance on secondary tasks in dual-task situations, and (d) impaired task-switching performance.

Attentional control theory also makes more specific predictions about the factors determining the effects of anxiety in all four areas, predictions supported by the available evidence. For example, distraction effects in high anxiety are predicted to be greater when the distracting stimuli are threat related or when the task is demanding of the resources of the central executive. In dual-task studies, attentional control theory predicts that adverse effects of anxiety on secondary task performance should occur mainly when secondary task stimuli are nonsalient or inconspicuous (e.g., presented in the periphery, less salient than primary task stimuli, or presented much less often than primary task stimuli). These predictions have all been confirmed. The predictions from attentional control theory regarding dual-task performance differ substantially from those following from Easterbrook's (1959) hypothesis, generally regarded as the dominant theory of anxiety and attention. For example, Staal (2004, p. 33) concluded that "the majority of the field has converged on the notion that stress and workload reduce cue utilization, shrink the perceptive field, or reduce an individual's environmental scan."

Attentional control theory is based in part on attentional processes emphasized in contemporary theories of attention. It is preferable to base theories of anxiety and attention on the insights of cognitive psychologists into the nature of the human attentional system than to focus on theoretical ideas (e.g., automatic narrowing of attention) not forming part of current theories of attention.

### Future Directions

We consider four important future directions for research. First, there is a need for more research directly testing the theory. For example, it is assumed theoretically that the effects of anxiety on performance depend on the salience or conspicuousness of distracting stimuli, of secondary task stimuli in dual-task situations, and of the cues in prospective memory studies. However, this variable has not been systematically manipulated in these paradigms. More generally, certain assumptions of the theory have only been tested in a single paradigm and should be tested across other paradigms. For example, attentional bias in anxious individuals has been studied extensively in distraction paradigms, but has not been tested in dual-task or task-switching paradigms. According to attentional control theory, the effects of anxiety in these paradigms could be varied by manipulating the type of stimulus presented. Another theoretical assumption requiring more research is that anxiety impairs the inhibition and shifting functions of the central executive under nonstressful as well as stressful conditions, but generally impairs the updating function only under stressful conditions. There are very few studies investigating these functions in which situational stress was manipulated. Finally, there is much evidence indicating that anxiety has a greater adverse effect on processing efficiency than on performance effectiveness. However, most of the research indicating that anxiety has a greater adverse effect on processing efficiency than on performance effectiveness has used complex tasks involving various processes. Future research should consider efficiency and effectiveness in tasks providing relatively pure measures of inhibition and shifting.

Second, neuroimaging offers considerable potential for testing predictions of attentional control theory because it provides a valuable way of assessing processing efficiency. Nearly all research concerned with performance effectiveness and processing efficiency has relied exclusively on behavioral evidence. With such evidence, the assessment of processing efficiency is typically indirect and inferential. In contrast, neuroimaging (e.g., fMRI), when combined with measures of performance effectiveness (e.g., Santos et al., 2006), permits an assessment of processing efficiency based on activation within brain areas associated with attention. In addition, neuroimaging may allow more precise measures of component executive systems that are very difficult to separate out with behavioral measures.

Third, there is a need for more research focusing on the strategies used by anxious individuals when their processing becomes inefficient. Typically, they increase effort or motivation to maintain task performance. However, anxious individuals sometimes use other strategies. For example, they use a capacity-saving approach on analogical reasoning tasks, using suboptimal strategies that minimize demands on the central executive (Klein & Barnes, 1994; Tohill & Holyoak, 2000). Another strategy involves searching for elevated evidence requirements before responding. Thus, Geen (1985) found that anxious individuals set a more

stringent decision criterion than nonanxious ones for reporting signal detection of a signal. Tallis, Eysenck, and Mathews (1991) and Nichols-Hoppe and Beach (1990) obtained similar findings with different paradigms. As yet, there is insufficient knowledge of the factors determining the strategy used by anxious individuals on any given task.

Fourth, according to the theory, anxious individuals have less available processing capacity in key functions of the central executive than nonanxious ones. If we compared the performance of anxious individuals on a given task with that of nonanxious individuals performing the same task while concurrently carrying out a task imposing demands on attentional control within the central executive, there should be a similar pattern of performance in both cases. This general strategy was adopted by Tohill and Holyoak (2000) and by Waltz, Lau, Grewal, and Holyoak (2000) in studies using the same test of analogical reasoning that permitted attribute-based and relation-based responding. Tohill and Holyoak found that participants exposed to a stressful or anxiety-making procedure produced more attribute-based responses and fewer relation-based responses than those not exposed to it. They argued that this was because relational processing imposes greater demands on the central executive. Waltz et al. found that participants performing the analogical reasoning task concurrently with a second task requiring use of the central executive had more attribute-based and fewer relation-based responses than those not performing a second task. Thus, there were comparable effects on performance of anxiety and of increased demands on the central executive.

In sum, the integration of processing efficiency theory with attentional control theory provides a reasonably comprehensive account of some cognitive processes and mechanisms determining the effects of anxiety on performance. The available evidence provides support for all of the theory's major theoretical assumptions and indicates that it possesses some validity. It is for future research to investigate in more detail the cognitive processes altered by anxiety.

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