Clinical Applications of Continuous Performance Tests

Measuring Attention and Impulsive Responding in Children and Adults

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The boundary between behavior and biology is arbitrary and changing. It has been imposed not by the natural contours of the disciplines, but by lack of knowledge. As our knowledge expands, the biological and behavioral disciplines will merge at certain points, and it is at these points of merger that our understanding of mentation will rest on particularly secure ground... Ultimately, the joining of these two basic disciplines represents the emerging conviction that a coherent and biologically unified description of mentation is possible. (Kandel, 1985, p. 832)

All too often individuals, whether clinicians or researchers, adapt and develop evaluation tools to meet the need of a particular type of client or to address a specific theoretical question. These evaluation tools may then be modified repeatedly and employed with different populations or to address theoretical issues for which they were not originally developed. Over time, within each specialty area, research accumulates with regard to one variation of the task or another and in its use with a given population. Multiple extensions of research result, radiating from a central idea or basic task. Understandably, many clinicians or researchers may become familiar with only one variation of an evaluation procedure that is specific to their individual practice or research agenda. Such a narrow perspective as to the value and scope of related procedures can lead to undesirable consequences, including misinterpreting the results of other variations of the procedure.

This volume represents a substantial effort at synthesizing and critically evaluating the research on the continuous performance test (CPT) that has accumulated over the past 50 years. This is quite an undertaking since over 300 papers have been generated across a range of populations and ages with multiple variations in CPT task demands and parameters. The resulting knowledge-base is impressive and can now be accessed in this single volume.

The conceptualization and procedures associated with CPT tasks are especially alluring in relation to Kandel’s suggestion that the behavioral and biological sciences have points of merger. Why? Because there exists clear evidence that in many cases of neuropsychological disease or dysfunction, performance on CPT indices may be significantly impaired.
Thus for psychologists, the CPT may be viewed as tapping into more neurobiologically mediated processes, a point well addressed in this volume. However, to really appreciate the potential value and pitfalls in employing CPT procedures in research or clinical practice, we must have a critical understanding of the extant literature. It is for this reason that this volume is such a vitally important resource for clinicians and researchers alike.

As I read through this book, several clear messages emerge when all of the research is taken into account. First, any specific CPT may vary from another CPT procedure in not only the level of difficulty but in the task demands. Hence, interpretation of performance on any CPT can only be interpreted in relation to the research data regarding that particular CPT procedure. Clinical or theoretical hypotheses generated from one CPT procedure may not generalize to indices of performance derived from another variation of the CPT procedure.

Second, as is the case for all measures employed in clinical practice, standardization of administration must be the rule—both in practice and in the standardization process itself. In large part, the standardization and norming of CPT procedures has not been a particular strength of the literature, until recently. Standardization and appropriate task-specific norms are essential if the results of performance on CPT procedures are to have clinical or theoretical value.

Third, CPTs as a family of paradigms are clearly sensitive to a variety of central nervous system (CNS) disorders in both children and adults. There is a wealth of data available in this regard. However, sufficient evidence does not exist regarding the specificity of impairment for any particular CNS disorder or dysfunction. In this context then, performance in the impaired range on any CPT procedure should be viewed at best as a nonspecific pathognomonic sign of CNS dysfunction.

Fourth, in examining the literature, it is clear that a variety of CPT paradigms exist, some of which tap different sensory modalities and different aspects of cognitive processes. While related to my first point, this variability in procedures may be seen as desirable depending on the particular sensory or cognitive process believed to be deficient in that we may have available CPT procedures to assess attentional and executive control parameters in relation to those more specific sensory or cognitive processes.

Fifth, while performance on any given CPT procedure may most often be used in reaching a diagnosis of CNS dysfunction, performance measures from the CPT may be an optimal tool for use in the monitoring of attention and executive control in conjunction with treatment (medication or otherwise). Further, performance on the CPT may also be a useful tool for documenting disease progression, even when the initial behaviors of concern are not related to attention or executive control.
One of the most significant features of this book is the identification of the research needed to further develop the CPT as a more valuable tool for clinical diagnosis, the monitoring of treatment effects, and as a procedure for documenting disease progression in both children and adults. However, the authors of this volume also urge appropriate caution in the clinical use of CPT measures as a definitive diagnostic tool. The results of CPT procedures need to be interpreted clinically in relation to the constellation of performance on other behavioral, cognitive, and related neuropsychological measures and procedures.

Overall, this comprehensive and well-written volume fills a very significant void in the clinical and research literature in regard to the conceptualization and utility of CPT procedures in research and clinical practice. Not only have the authors accomplished a wonderful critical review of the literature regarding CPT procedures, but they have presented it in a carefully formulated way such that questions regarding the CPT can easily be addressed in one essential source. This is a major contribution to the literature.

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Preface

During the 1950s, a paradigm that has become known as the continuous performance test (CPT) was devised for specific research applications. This design was similar in some ways to measures of vigilance earlier in the twentieth century. The new design was quite successful and interested researchers in many areas of psychology, including the pure experimentalists as well as the applied researchers. The expansive research literature on the CPT suggests that variables measured by various CPT paradigms, of which there are many, are affected by many psychopathologies commonly encountered by psychologists as well as by trauma and physical disease.

During the 1990s, as a result of heavy marketing and the managed care movement, CPTs began to be used to establish specific diagnoses within psychology, most commonly Attention-Deficit/Hyperactivity Disorder (ADHD) and its subtypes. A few reviews of literature have been done dealing with specific aspects of CPT performance or a single psychopathology. Nowhere have we located a work that deals with the complexity of the various CPT paradigms themselves or with the multiple psychopathologies to which these paradigms have been applied. In fact, we were unable to locate a single study that compared CPTs with differing demands across populations. Our search for improved clinical and research applications of the CPT gave rise to the current volume.

In this work, we hope to provide a reference source for those who would apply various CPTs in their clinical practice as well as those who are engaged in research with these interesting and, now, mainstay paradigms. We begin with a description of the various neural substrates of CPT variables as they are now understood. The many inventive CPT paradigms are next described before we move to an assessment of the psychometric characteristics of some of the commercially available CPTs. We next look at the association of various demographic characteristics and other status variables to performance on CPTs. The use of various CPT paradigms in the diagnostic process itself is then reviewed for children, youth, and adults; findings here have been similar across age levels in some areas, yet quite disparate in others. Medication effects are assessed as well, and we find that many of the existing CPT paradigms are in fact quite sensitive to medication effects and therefore may be useful in monitoring treatment as well.
as assessing undesirable cognitive side effects of many psychoactive medications. The potential for the use of CPTs in monitoring other forms of treatment (e.g., attention training) is reviewed as well.

We hope to inspire additional, much needed research as noted and delineated throughout the book and summarized in our final chapter. Despite nearly a century of research on tasks associated with vigilance and more complex CPT designs, there is a great deal that remains to be done. Large-scale multisite studies specific to the use of CPTs in differential diagnosis and treatment monitoring continue to be needed. The CPT has sufficient promise to warrant grant support for these endeavors.

ACKNOWLEDGMENTS

We offer our appreciation to Jennifer J. Moore for her extensive work in developing the literature searches and reviews with us in the preparation of this volume. Our Wiley editor, Tracey Belmont, who pursued this volume with us and then showed tremendous patience as we continued to find literature and revise this work, also deserves our appreciation. We wish to thank Rafael Klorman for providing a much-needed figure from his research with the CPT and George Hynd for agreeing to write the Foreword for us. In addition, Cyndi would like to express her appreciation to Christine French and Monica Wolfe for their assistance in manuscript preparation and to her colleagues for their continued support. Cecil once again acknowledges his debt to Julia, who keeps him centered and without whose emotional support he could not be successful. Patricia would like to express her appreciation to family, friends, and the Warm Springs Counseling Center (WSCC) staff for their support, encouragement, and sense of humor throughout this endeavor. To those who read this work, we offer our appreciation for working through the often complex material that we have tried so hard to present in a logical fashion. We hope you benefit in some way from our efforts.

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CECIL R. REYNOLDS
PATRICIA A. LOWE
CHAPTER 1

Neurobiology of Attention and Executive Control

Before discussing the clinical uses and limitations of the continuous performance test (CPT), it is important to appreciate what we know about attention and executive control and their importance to clinical neuropsychology in terms of both assessment and rehabilitation. Problems with attention are inherent in a multitude of disorders, but most frequently noted in conjunction with Attention-Deficit/Hyperactivity Disorder (ADHD) and, in adults, schizophrenia. Attention problems in one form or another are associated with many neurological disorders. Hemineglect or hemiattention, for example, is a common manifestation of unilateral lesions due to stroke (R.A. Cohen, Malloy, & Jenkins, 1999; Mesulam, 1981, 1985a, 1985b). Neurological disorders associated with more diffuse damage (e.g., generalized seizures, Alzheimer’s disease) and diffuse trauma such as anoxic encephalopathy often include behavioral manifestations of impaired attention as well as impaired executive control (R.A. Cohen et al., 1999). At the same time, impairment of attention is one of the more common symptoms of multiple sclerosis (R.A. Cohen, 1993b), with problems of slowed processing as well as attentional control. In this regard, attention can be seen as involving motor, cognitive, and social processes (Sohlberg & Mateer, 1989a, 1989b). Attentional deficits are also associated with other neurological disorders. The notion of attention and executive control function as related to the integrity of the frontal lobes is derived from clinical evidence and behavioral correlates of traumatic brain injury (TBI). The most common complaints of patients following TBI are attention and concentration problems, coupled with memory deficits. It has been argued that memory relies on the neural traces of attention and therefore that attention is key to the formation of memory (R.A. Cohen, 1993b; Sohlberg & Mateer, 1989a) and, subsequently, has an impact on cognitive functioning. Theoretical foundations and models for
attention and executive function and their proposed neurological substrates are presented next.

**ATTENTION AND EXECUTIVE CONTROL**

Attention is not unitary; rather, it is a nebulous and complex construct (Mirsky, Fantie, & Tatman, 1995). Zubin (1975) suggested that attention could be conceptualized as having multiple components or elements. Psychiatry (e.g., D. Siegel, 2000) views attention as the process that controls the flow of information processing in the brain, making it a fundamental, key element of all cognitive tasks. Among patients with psychiatric disorders, three components of attention are used clinically to describe attentional defects: selectivity, capacity, and sustained concentration. Ward Halstead (1947), an early pioneer of clinical neuropsychology, included attention and the related concept of vigilance in his theory of the biological basis of intelligence. Neuropsychologists, at the most basic level, conceptualize attention as involving selective processing and awareness of stimuli (Mesulam, 1985a, 1985b). In particular, the term “attention” may be used to refer to the following: (1) initiation or focusing of attention; (2) sustaining attention or vigilance; (3) inhibiting responses to irrelevant stimuli or selective attention; and (4) shifting of attention (Denckla, 1996; Mirsky, 1989; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991; Sohlberg & Mateer, 1989a; Zubin, 1975). Others have included encoding, rehearsal, and retrieval as components of attentional functions (Mirsky, 1989; Mirsky et al., 1991). In addition, the construct of attention has been conceptualized in terms of sensory attention as well as motor intention (Heilman, Watson, & Valenstein, 1985). Table 1.1 provides a list of components of attention that are commonly addressed.

Broadbent (1953, 1957) viewed attention from the perspective of the perceptual system and information processing. He proposed that the capacity to take in information is limited; therefore, information that is not relevant needs to be filtered out. The likelihood that information would be filtered out or in was viewed as dependent on characteristics of the stimulus (i.e., intensity, importance, novelty). Notably, some of these same stimulus characteristics, as well as others, have a demonstrated impact on attention as measured by the CPT and are discussed in more depth in Chapter 2.

A second early theory of attention focused on arousal (Hebb, 1958; Moruzzi & Magoun, 1949; Samuels, 1959). Based on the arousal theory, optimal levels of arousal (or alertness) are necessary for effortful, organized function, and sensory stimulation provides an impetus for arousal.
Pribram and McGuinness (1975) described arousal as a short-lived response to a stimulus. In the clinical arena, assessment of attention is perceived as entailing more than basic awareness and is concerned with more than arousal level. Related to but distinct from attention, arousal can be defined as the general state of the individual that allows for and affects attentional processes (Parasuraman, 1984a, 1984b).

In view of the complexity of attention and its component processes, Mirsky (1987) proposed restricting the myriad aspects of attention to the focusing of attention, sustaining of attention, and shifting of attention. Using these three components as organizers, selective attention, for example, becomes part of the process involved in focusing attention or, if deficient, in the level of distractibility. Selective or focused attention requires optimal arousal as well as information-processing capacity (Mirsky et al., 1991; Pribram & McGuinness, 1975). In contrast, sustained attention is the ability to maintain that focus over time (Mirsky et al., 1991). It has been argued that sustained attention as well as focused attention involve selective attention, attentional capacity, and response selection over time (R.A. Cohen & O’Donnell, 1993b). The shifting of attention is considered to reflect the need for flexibility and adaptation of various elements of attention as well as involving the capacity to inhibit the previously initiated attentional response (Mirsky, 1987; Mirsky et al., 1991).

Similarly, and more consistent with the importance of arousal to other components of attention, van Zomeran and Brouwer (1994) included arousal as one of two components of their model of attention, with the ability to sustain attention incorporated as a function of arousal. The second component of their model is selective attention, which is composed of focused attention and divided attention. Thus, the van Zomeran and

<table>
<thead>
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<th>Components of Attention*</th>
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<tr>
<td>Arousal/alertness</td>
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<tr>
<td>Motor intention/initiation</td>
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<tr>
<td>Selective attention</td>
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<tr>
<td>Focusing of attention</td>
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<tr>
<td>Inhibiting/filtering attention</td>
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<tr>
<td>Divided attention</td>
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<tr>
<td>Encoding, rehearsal, and retrieval</td>
</tr>
<tr>
<td>Sustaining attention/concentration</td>
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<td>Shifting of attention</td>
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* Based on Mirsky et al. (1991); Stankov (1988); van Zomeran and Brouwer (1994).
Brouwer model of attention incorporates the element of arousal as well as the information-processing components of attention included in Mirsky’s (1987) model. Based on a factor analytic study, Stankov (1988) suggested three components of attention: concentration or sustained attention, attentional flexibility or the ability to shift attention, and perceptual or processing speed. All three components were found to be strongly associated with measures of fluid ability (i.e., novel problem solving). Others have organized attentional processes by virtue of their information-processing demands (i.e., the extent to which flexibility is required) and the extent to which the attentional process is automatic or controlled (Posner, 1978; Shiffrin & Schneider, 1977). Controlled attentional processes are those that require effort, are serial, and are subject to interference. The controlled processes are believed to be slower and to have a more limited processing capacity as compared to the processing that is effortless and without subjective awareness, or automatic processing (Posner, 1978).

Attention is one of many processes incorporated into the larger construct of executive function. Executive function is a more general construct that includes such abilities as sustaining attention and maintaining a response set, shifting of set, problem solving, planning and follow-through (R.A. Cohen, 1993d). Executive control is that aspect of executive function that is involved in self-regulation, self-direction, goal directedness, and response inhibition as well as the actual capacity to inhibit the response (Barkley, 1997a, 1997b; R.A. Cohen, 1993d). These components of executive control are identified in Table 1.2.

Executive control is closely intertwined with attentional processes due to the need for attentional shifts and attentional flexibility in the regulatory and inhibition processes (R.A. Cohen, 1993d). Both executive control and attention are also necessary for initiation or generation of the response to a specific stimulus, for maintenance of the response or shifting of the response, and for flexibility of responding to meet changing demands (R.A. Cohen, 1993d; Whyte, 1992).

<table>
<thead>
<tr>
<th>Table 1.2 Components of Executive Control</th>
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<tr>
<td>Self-direction</td>
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<td>Goal directedness</td>
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<td>Self-regulation</td>
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<td>Response selection</td>
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<td>Response inhibition</td>
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NEUROPSYCHOLOGICAL MODELS OF ATTENTION

The multifaceted nature of attention and executive control makes it difficult to map the behaviors of interest directly onto neurological components. J. Swanson, Cantwell, Lerner, McBurnett, and Hanna (1991) have argued, for example, that attentional deficits cannot be linked directly to cognitive operations nor to specific neural systems. When the arousal theory was the primary model of attention, the focus was on those neural structures associated with physiological arousal (e.g., Lindsley, Bowden, & Magoun, 1949; Moruzzi & Magoun, 1949). Specifically, there was a focus on the two pathways for sensory projections onto the cortex: the pathway through the thalamus and the pathway through the reticular activating system (RAS). Damage or dysfunction of the RAS is believed to have an impact on arousal and activation levels (R.A. Cohen et al., 1999). Over time, multiple models of attentional processes of increasing complexity have been posited (e.g., Goldman-Rakic, 1988; Heilman et al., 1985; Luria, 1966; Mesulam, 1981, 1985a, 1985b; Petersen, Fox, Posner, Mintur, & Raichle, 1989; Posner, 1988; Posner & Petersen, 1990; Pribram & McGuinness, 1975; Stuss & Benson, 1984, 1986).

With increasing frequency, models of attention and executive control involve a number of cortical structures and systems (van Zomeran & Brouwer, 1994). Functional system models of attentional processes include both peripheral autonomic and central nervous system (CNS) correlates of attention (R.A. Cohen & O’Donnell, 1993b). At the same time, current functional system models include cortical and subcortical structures as well as connecting pathways and projections, including those identified with the arousal theory. The major models are reviewed briefly to provide a backdrop against which to evaluate the clinical uses of the CPT. It is important to note that whereas earlier models tended to emphasize the RAS, there is increasing emphasis on the frontal lobes (van Zomeran & Brouwer, 1994). The major components of the various systems (e.g., RAS, frontal lobe, basal ganglia) are depicted in Figure 1.1.

Executive functions, including attentional processes and executive control, are thought to be mediated predominantly by the frontal system and the pathways connecting the frontal lobes with other cortical and subcortical areas (Fuster, 1980; Milner, 1963, 1964). The frontal lobes have been found to constitute a complex neurological and functional system (Luria, 1966; Welsh & Pennington, 1988). Within the frontal lobes, the prefrontal cortex is believed to integrate and regulate the behaviors needed to execute a planned and coordinated sequence (Fuster, 1989; Ingvar, 1985; Luria, 1966; Norman & Shallice, 1985; Stuss & Benson, 1984). Among those behaviors that are believed to be tied into frontal lobe function are...
the ability to (1) maintain a response set in a goal-directed fashion (Luria, 1966); (2) carry out a strategic plan in sequence (Luria, 1966); (3) plan and self-monitor one's own behavior (Flavell, 1971); (4) attend to and make use of environmental cues (Passler, Isaac, & Hynd, 1985); (5) focus attention (R.A. Cohen et al., 1999); and (6) form a mental representation of the task (Luria, 1966). The complexity and systemic nature of the frontal lobes are evident in the interconnections of the prefrontal cortex with the limbic system (thus incorporating motivation), the RAS (arousal), the posterior association cortex, and the motor regions within the frontal lobes themselves (Barbas & Mesulam, 1981; Johnson, Rosvold, & Mishkin, 1968; Porrino & Goldman-Rakic, 1982; Welsh & Pennington, 1988).

Mesulam (1981) was one of the first to offer a model of an integrated attentional system. His model was specific to understanding the phenomenon of those individuals who exhibited hemiattention or hemineglect as a result of brain damage and, as such, focused on spatial location. The model, however, continues to be viewed as a viable framework for understanding attentional processes. Mesulam posited that attentional processes involved the reticular system, the limbic system, the frontal cortex, and the posterior parietal cortex. Subcortical influences from the limbic system (including the cingulate), RAS, and hypothalamus are viewed as a systemic matrix that is necessary for the control of attention (Mesulam, 1985a, 1985b). The frontal lobes both are influenced by and have an influence on the reticular system via afferent and efferent pathways. In this model, the frontal lobes...
are involved in fixating or selective attention to the target as well as scanning, reaching, and so on. The contribution of the reticular system is preparedness or level of arousal as well as vigilance or maintenance of that level of arousal. Within the limbic system, Mesulam theorized that the cingulate gyrus in particular was involved in attentional processes due to its role in the individual’s motivational state. Other researchers have found some indications that the anterior cingulate is involved in attentional processes as well (Petersen et al., 1989). Cingulate lesions are believed to have the greatest impact on motor intention as opposed to attentional control (R.A. Cohen et al., 1999).

The orbital prefrontal cortex is seen as modulating those impulses that originate in the limbic system and the hypothalamus (R.A. Cohen, 1993a, 1993c). Finally, the posterior parietal cortex is viewed as providing an internal sensory map. Neural systems of the parietal lobe are believed to be essential in selective attention. As such, sustained attention is the result of the interaction of the neural system of the frontal lobes, limbic structures, and subcortical structures and may be disrupted to varying degrees by compromise of virtually any structure within these systems (R.A. Cohen, 1993a, 1993c).

Luria (1966) posited that executive functions were of importance in the control of behavior with particular emphasis on the prefrontal cortex. The attentional system was central to his models of normal and abnormal brain function. Approaching attention from a combination of perspectives, including cognitive processing, Luria proposed two attentional systems: reflexive and nonreflexive. The reflexive system includes the orienting response (OR) and appears early in development. In contrast, the nonreflexive system develops at a slower rate, is the result of social learning, is associated with cognitive and linguistic mediation of behavior, and is necessary for sustained attention (R.A. Cohen & O’Donnell, 1993b, 1993d). Based on clinical evidence, Luria suggested that the limbic system and the frontal lobes mediated both attentional activation and inhibition. Clinical studies, for example, found that patients with damage to the limbic system were more likely to tire easily, be distractible, and be unable to sustain attention over time. Similarly, studies of patients with severe frontal damage consistently reported difficulty with sustaining attention and resisting distractions.

A second model, the frontal-diencephalic-brainstem system (FDB), was offered by Stuss and Benson (1984, 1986). As with Mesulam’s model (1985a, 1985b), the reticular system is responsible for levels of alertness. While continuing to include the reticular system and the frontal lobes consistent with Mesulam’s model, Stuss and Benson placed additional emphasis on the role of the frontal-thalamic gating system and the various projections associated with the thalamus. The frontal-thalamic gating