Sustained and Transient Attention in the Continuous Performance Task

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One of the most frequently applied methods to study abnormal cognition is the Continuous Performance Task (CPT). It is unclear, however, which cognitive functions are engaged in normal CPT performance. The aims of the present study were to identify the neurocognitive functions engaged in the main variants of the CPT and to determine to what extent these variants differentially engage these functions. We hypothesized that the main CPT versions (CPT-X, CPT-AX, CPT-Identical Pairs) can be distinguished by whether they demand sustained or transient attention and sustained or transient response preparation. Transient attention to objects like letters or digits, that is, the need to switch attention to different objects from trial to trial, impairs target detection accuracy relative to sustained attention to a single object. Transient response preparation, that is, the possibility to switch response preparation on and off from trial to trial, improves response speed relative to having to sustain response preparation across all trials. Comparison of task performance and Event-Related brain Potentials (ERPs) of healthy participants obtained in the main CPT variants confirmed these hypotheses. Behavioral and ERP measures indicated worse target detection in the CPT-AX than in the CPT-X, consistent with a higher demand on transient attention in that task. In contrast, behavioral and ERP measures indicated higher response speed in the CPT-AX than in the CPT-X, associated with more response preparation in advance of the targets. This supports the idea of increased transient response preparation in the CPT-AX. We conclude that CPTs differ along at least two task variables that each influences a different cognitive function.

Introduction

Continuous Performance Tasks (CPTs) are among the most frequently applied methods to study cognitive deficits in diverse disorders. They have been used extensively to study cognitive dysfunction in schizophrenia, attention-deficit hyperactivity disorder, affective disorder, tic disorder, conduct disorder, learning disabilities, brain damage patients, and to study the cognitive effects of lithium, methylphenidate, anti-psychotics, etc. For recent reviews and overviews, see Borgaro et al. (2003), Nichols and Waschbusch (2004) and Riccio, Reynolds, Lowe, and Moore (2002).

The cognitive function held responsible for impaired performance in CPTs is still unclear, however, varying widely from study to study. Impaired CPT performance has been associated with very general notions as impaired "neurobehavioral functioning", "attentional functioning" and "frontal functioning". More specific interpretations are that the CPT is a measure of sustained attention (Borgaro et al., 2003), or of the ability to rep-

resent and maintain context information necessary to guide appropriate task behavior (Cohen & Servan-Schreiber, 1992). Also, many findings point to motor related preparatory functions (Goldberg & Weinberger, 1995).

An important complicating factor is that very different versions of the CPT have been used under the assumption that the CPT is a standard test of cognitive function, although no systematic investigation in healthy controls of the cognitive functions engaged in different CPTs has been conducted. Consequently, many authors have complained that it is very difficult to (1) compare CPT studies on the same patient groups or the same type of treatment, (2) compare CPT studies between patient groups or treatments (see e.g., Heinrichs, 2001; Riccio et al., 2002), and (3) infer what cognitive functions are indexed by the CPT (see e.g., Borgaro et al., 2003; Cohen & Servan-Schreiber, 1992; Elvevag, Weinberger, Suter & Goldberg, 2000; Goldberg & Weinberger, 1995; Hazlett, Dawson, Schell & Nuechterlein, 2001).

The aim of the present study was to identify the neurocognitive processes engaged in the main variants of the CPT. We first briefly describe the CPT versions that are most often applied. Next, we describe several influential proposals to account for impairment of CPT performance and some illustrating evidence. We then identify two task variables that have been largely neglected in the literature on CPT performance, but can be used to (1) systematically categorize different CPT versions, (2) estimate their effect on different cognitive functions, and (3) reconcile different interpretations of impairment of CPT performance. Finally, we verified the role of these task variables by comparing task performance and Event-Related brain Potentials (ERPs) in the main CPT variants with healthy controls.

In the original and most simple CPT version, known as the CPT-X (Rosvold, Mirsky, Sarason, Bransome & Beck, 1956; see also Orzack & Kornetsky, 1966), the participants are shown a random sequence of different letters with a rate of about one per second. The instruction is to push a button only when the target letter X is shown and not to respond to any other letter. The target letter usually has a low probability (around .20) to be presented. Nuechterlein, Parasuraman and Jiang (1983) introduced a second variant, the degraded stimulus CPT. This version is identical to the CPT-X, except that the stimuli are physically degraded, which increases the perceptual demands of the task. A third version is the CPT-AX, also developed by Rosvold et al. (1956). In the CPT-AX the instruction is to respond to an X, but only if it was preceded by the letter A. The cue A and the target X usually have a low probability to be presented (.20) amidst other letters (B, C, D, etc). Sometimes a CPT-AX with a high probability of an AX sequence was used (.80; Servan-Schreiber, Cohen & Steingard, 1996). Finally, in an often used variant, called the CPT-Identical Pairs (Cornblatt, Risch, Faris, Friedman, & Erlenmeyer-Kimling, 1988), a response is required to the second of every pair of two identical successive letters (for details see Borgaro et al., 2003, and Riccio et al., 2002).

A highly influential hypothesis states that the main cognitive function underlying CPT performance is a subcomponent of working memory: the ability to represent and maintain context information necessary to guide appropriate task behavior (Barch et al., 2001; Braver & Cohen, 1999; Cohen, Barch, Carter & Servan-Schreiber, 1999; Cohen & Servan-Schreiber, 1992; Servan-Schreiber et al., 1996). This interpretation has been successfully implemented in functional (Cohen & Servan-Schreiber, 1992) and neurobiological models (Braver & Cohen, 1999; Grace, 2000; Levy & Farrow, 2001). These models assume that context information consists of the instruction what to do with what stimulus (CPT-X) and sometimes also of information about the previous stimulus (CPT-AX, CPT-Identical Pairs). This context information is assumed to be maintained in advance of stimulus presentation in temporary stores of working memory by executive mechanisms (Baddeley,

2001; Goldman-Rakic, 1999). Only by comparing this context with the incoming stimulus, a correct decision about the response to the stimulus can be made. An impairment of CPT performance therefore is assumed to reflect a deficit in the maintenance of context information. It is further assumed that because the CPT-AX and the CPT-Identical Pairs have a higher "memory load", that is, more information needs to be maintained in memory than in the CPT-X they are more difficult to perform and therefore more sensitive to impairment of the maintenance function.

Other hypotheses about the cognitive function underlying CPT performance point to the possible role of motor related functions (Epstein, Johnson, Varia & Conners, 2001; Fallgatter, 2001: Flint & Turek. 2003; Goldberg & Weinberger, 1995; Ornitz, Gehricke, Russell, Pynoos & Siddarth, 2001; van den Bosch, Rombouts & van Asma, 1996). Goldberg & Weinberger (1995) concluded on the basis of many arguments, that "attention as deployed in the CPT may reflect response readiness rather than actual vigilance".

Both hypotheses assume that CPT performance varies along a single dimension of cognitive function, either maintenance of information in working memory or response preparation. One reason for this single-dimensional view is that in many cases these hypotheses were tested with measures that allowed observation of only a single dimension of task performance, thereby hiding the other dimension for analysis. For example, Coons and colleagues (1981) and Borgaro et al. (2003) found more omission errors and smaller d' in the CPT-AX than in the CPT-X and proposed this indicated an impairment of sustained attention. Unfortunately they did not record Reaction Times (RTs), so they had no data about differences in performance speed in the two tasks.

There are two studies in which both omission errors and RT were recorded. Kaskey, Salzman, Ciccone & Klorman (1980) studied the effect of lithium in manic (bipolar disorder) patients in a pre-/ post-treatment design with the CPT-X and CPT-AX, and Dias, Foxe & Javitt (2003) analyzed brain potentials in many CPT variants performed by healthy participants. Unfortunately, Kaskey et al. (1980) did not present statistical tests or a discussion of the task differences found, but their Table 1 shows that in the pre-lithium phase of the design there were more omission errors and smaller d', but also more false alarms and faster RTs in the CPT-AX than in the CPT-X. Dias et al. (2003) also did not present tests or a discussion of the effects they show in Table 2 of the control tasks they used (in our terminology: CPT-X, CPT-AX and CPT-Identical Pairs). Also this table shows more omissions but faster RTs in the CPT-AX than in the CPT-X.

These findings indicate that, compared to the CPT-X, performance of the CPT-AX deteriorates (omission errors) and improves (RT) at the same time. This is paradoxical and hard to explain by single-dimensional hypotheses. The maintenance hypothesis predicts that the increased need for maintenance of context information in the CPT-AX would increase the frequency of omission errors and would increase RT (due to comparison of the current stimulus with the previous stimulus). The response preparation hypothesis predicts that the increased preparation on the basis of cue A for the target response in the CPT-AX would decrease the frequency of omissions errors and would decrease RT compared to the CPT-X. We believe that these findings suggest that variation in CPT performance is driven by at least two cognitive functions, stimulus detection and response preparation. This is true when performance varies between CPT versions and could also be the case when performance of a particular CPT varies as a function of a particular diagnosis.

We propose to categorize the main CPT versions along two different task variables, each influencing an independent cognitive function. The first variable differentiates tasks that require sustaining attention to a single stimulus (sustained attention tasks), and tasks that require frequently switching attention to different stimuli (transient attention tasks;

Eimer, 1997). In sustained attention tasks, participants are instructed in advance of the task to attend to the same specific stimulus across all stimulus presentations in the task. The CPT-X and the degraded stimulus CPT conform to this criterion and thus can be called sustained selective attention tasks. In transient (cued) attention tasks, participants are instructed by a precue telling them what stimulus to attend next. In this case, the instruction varies across stimulus presentations. The CPT-AX and the CPT-Identical Pairs conform to this criterion of transient selective attention tasks[1].

The effect of varying this task factor depends on the stimuli used. For example, Eimer (1996, 1997) found that sustained or transient attention produced benefits in target detection, depending on the stimulus features to be attended: spatial location or color/shape. If spatial location was attended, transient attention produced better target detection than sustained attention. If color or shape was attended, sustained attention leads to better target detection than transient attention[2].

The second task variable that differentiates CPT tasks, concerns tasks that predominantly engage sustained response preparation and tasks that predominantly engage transient response preparation. In sustained response preparation tasks, every stimulus is a potential target that may require a response, so some level of response preparation is required in advance of every stimulus (e.g., CPT-X). In transient or cued response preparation tasks, only cued targets require a response. In this case, response preparation is only required after a cue signaling a potential future target (e.g., CPT-AX). Many studies have shown that cued response preparation produces superior task performance compared to sustained response preparation (Brunia, 1993; Rosenbaum, 1980). Moreover, it is known for a long time that response preparation can be maintained at an optimal level for only brief periods of time (i.e., a few hundred ms; Alegria, 1974).

In summary, CPTs can be classified along two dimensions, each representing an independent task factor and influencing a different cognitive function. The first concerns variation in the demand to switch selective attention in a task, and the second concerns variation in the demand to prepare motor responses in a task. In this classification the CPT-X is a sustained attention—sustained response preparation task, because the letter to attend is constant in the task and because every stimulus is a potential target. The CPT-AX with low and high probability AX are transient attention—transient response preparation tasks, because the letter to attend depends on the cue (if A is presented, attend the X, if not

[1]We use the concept of selective attention here in the sense of voluntary orienting of attention to a location in space or an object feature, on the basis of a verbal instruction or a cuing stimulus. Recent studies have shown that voluntary selective attention to a particular stimulus and its demands produces prolonged activity in parietal areas of cortex in advance of stimulus presentation, both for verbally specified stimuli and for stimuli specified by a cuing stimulus (Corbetta & Shulman, 2002). This activity was furthermore independent both of activity produced by the cue and that produced by the target stimulus, and therefore reflects the activity of top-down control processes. If instructions vary from trial to trial, selective activity is varied due to top-down control mechanisms, and therefore is in a transient mode. When instructions are the same across all trials of a task, selective activity is maintained as a constant across trials, and therefore is in a sustained mode.

[2]In terms of models of attention (for example, Fan, McCandliss, Sommer, Raz, & Posner, 2002), variation of the transient/sustained attention dimension would influence the voluntary orienting of attention, the executive system, and possibly also the vigilance system, because different types of stimuli (brightness versus color) may differ in alertness-evoking capacity. In terms of models of working memory (Baddeley, 2001), transient and sustained attention would influence the central executive, but also the visual spatial scratch pad and phonological short term memory systems. Transient attention may lead to switching between activity patterns in all three of these working memory components. Response preparation is a result of executive working memory mechanisms that make use of the information maintained to plan future behavior.

an A is presented, attend the A), and advance response preparation is only called for if A is presented. The CPT-Identical Pairs is a transient attention—sustained response preparation task, because the letter to attend depends on the previous letter and all subsequent letters are potential targets.

In combination, these dimensions can explain previous and predict future performance in different CPTs. Eimer (1997) showed that (non-spatial) sustained attention tasks produce better target detection than transient attention tasks. Therefore, target detection should be better in the CPT-X than in the CPT-AX. Furthermore, the general finding that transient response preparation results in faster performance than sustained response preparation predicts faster performance in the CPT-AX than in the CPT-X. This neatly explains the paradoxical findings by Kaskey et al. (1980) and Dias et al. (2003): less omission errors and larger d', but also slower RTs and less false alarms in the CPT-X than in the CPT-AX.

To verify the critical role of these task variables, we recorded behavioral measures and Event-Related brain Potentials (ERPs) from healthy participants performing several CPT versions, modelled after Rosvold et al., (1956) and Gordon (1986). We use standard abbreviations for the stimuli after Michael et al. (1981) and Servan-Schreiber et al. (1996). In the CPT-X, there are two interesting stimulus types, the target X and the set of nontargets (e.g., A, D, F, S, etc.; usually six or more letters or digits) collectively called Y. The participant must attend to and prepare for the letter X and its associated response in advance of every stimulus. In the CPT-AX, there are four types of cue-stimulus sequences: AX, AY, BX and BY. The presentation of a B, Y or X prompts to attend next to the letter A and not to prepare a response. Presentation of the cue A prompts to attend next to the letter X, and to prepare the associated response. Upon presentation of an X (AX sequence), the already prepared response to X has to be executed, but upon presentation of the Y (AY sequence), the advance preparation must be inhibited to prevent an error response. In the BX sequence, the X is presented unexpectedly and the response tendency associated with X must be stopped. In the BY sequence there is no preparation for, nor a response tendency to Y.

To study more precisely the role of motor preparation, we manipulated the cognitive function of response choice in the tasks. In each CPT, we defined two different X targets, each demanding a different overt response (for example, X1 calling for a left hand button press and X2 demanding a right hand button press). Increasing the number of motor response alternatives increases the time needed for motor preparation to targets but does not influence other attentional or cognitive functions engaged in the task (Donders, 1969; Hackley, Schaeffer & Miller, 1990; Smid, Fiedler & Heinze, 2000). As a control, we ran an experiment in which only a single response was required in the tasks.

To study more precisely the source of false alarm errors in the CPT-AX, we designed a third task in which the response demanded by X was cued by one of two different A stimuli. If A1 was presented, a subsequent X required one response (for example, a left hand button press) and if A2 was presented a subsequent X required the other response (a right hand button press). Thus, in this task, called the CPT-AcX, the cue A makes it possible to selectively prepare the required motor response in advance of X. We expected that this selective motor preparation would increase false alarm frequency. This task also makes it possible to generalize the findings with the present response choice variants of the CPT-X and CPT-AX to the traditional Go/Nogo CPTs. Specifically, selecting and preparing the response on the basis of cue A in advance of X makes the CPT-AcX equivalent to the traditional CPT-AX, in which A signals the exact motor response to be be prepared (Hackley et al., 1990; Smid et al., 2000).

In summary, we applied three different CPTs. In the CPT-X, attention to and preparation for the X target must be sustained during the entire task. In the CPT-AX, attention to and preparation for the X are only needed after cue A and are therefore transient. In the CPT-AcX, attention to and preparation for X are also transient, but the cue A also allows for selective preparation of the response demanded by X. We recorded RT and frequency of omission and false alarm errors. Our two-dimensional classification predicts that omissions are more frequent in the CPT-AX than in the CPT-X, supporting the hypothesis that in the CPT-AX transient attention impairs target detection. It further predicts that RTs are faster in the CPT-AX than in the CPT-X, supporting the hypothesis that transient response preparation improves response speed in the CPT-AX .

To identify the neural mechanisms underlying sustained or transient attention and preparation in the CPT, we derived three well-established Event-Related brain Potentials (ERPs) from the Electroencephalogram (EEG). First, the visual selective processing of attended stimuli relative to unattended stimuli can be observed in the ERP as a Selection Negativity (SN; for reviews, see Hillyard & Picton, 1987; Kenemans, Kok, & Smulders, 1993; Näätänen, 1992; Smid, Jacob, & Heinze, 1999). The SN is obtained by subtracting the ERPs to stimuli that do not call for further processing (e.g., Y) from the ERPs to stimuli that do call for further processing (e.g., X). It typically starts about 150 ms after stimulus presentation and is largest in amplitude over the posterior scalp (visual areas). Eimer (1996,1997) found that the SN is delayed in time and decreased in amplitude if attention is transient relative to when attention is sustained. If we find that the SN in the CPT-AX is delayed in time and decreased in amplitude relative to the SN in the CPT-X, this would further support our hypothesis that in the former transient attention dominates, while in the latter sustained attention dominates.

Secondly, transient preparation on the basis of a precue can be observed in the ERP with the Contingent Negative Variation (CNV; Walter, Cooper, Aldridge, McCallum & Winter, 1964). The CNV is a negative EEG potential over the central area of the scalp that develops after presentation of a warning signal and in anticipation of an upcoming event that requires a cognitive or motor action. The late part of the CNV (the terminal 500 ms) is associated with perceptual preparation and response programming (Brunia, 1993; Brunia, Haagh & Scheirs, 1985; Ulrich, Leuthold & Sommer, 1998). We applied the late CNV to observe whether in the CPT-AX the cues A are used to transiently prepare for a target X. If so, cues A should produce a late CNV and cues B should not, providing further support that transient response preparation determines response speed in the CPT-AX.

Thirdly, selective motor preparation can be observed in the ERP with the Lateralized Readiness Potential (LRP; cf. Coles, Smid, Scheffers & Otten, 1995; Hackley & Miller, 1995; Leuthold, Sommer & Ulrich, 1996). The LRP is derived by subtracting the hemispheric asymmetry in the ERP over the motor cortices obtained on left hand response trials from that obtained on right hand response trials. This subtraction ensures that hemispheric ERP asymmetries that do not vary with response hand are eliminated. We used the LRP in three ways. To distinguish the pre-motor component of RT and the motor component of RT, we averaged the LRP synchronized to the stimulus in one analysis (stimulus-locked LRP) and synchronized to the keypress in a second analysis (response-locked LRP; Osman & Moore, 1993; Smid et al., 2000). The onset latency of the stimulus-locked LRP indexes the time at which pre-motor processing of the stimulus (including response selection and programming) is finished and the onset latency of the response-locked LRP indexes the time at which motor preparation of the response starts prior to the keypress. The amplitude of the response-locked LRP can be used as an index of the extent of motor preparation (cf., Hackley & Miller, 1995; Smid et al., 2000), that is, a larger LRP is associated with more response preparation.

We applied the LRP to obtain additional evidence for our task classification and to determine whether transient preparation in the CPT-AX involves pre-motor processes, motor processes or both. If we find that the stimulus-locked LRP starts earlier in the CPT-AX than in the CPT-X, it suggest faster pre-motor processing in the CPT-AX. If motor processes are involved we should find that the response-locked LRP in the CPT-AX starts closer to the button press and is smaller in amplitude (less preparation needs to be done after target presentation) than in the CPT-X. If only pre-motor processes are involved, the response-locked LRPs should be the same in the CPT-AX and the CPT-X. In the CPT-AcX we used a third LRP analysis. We expected that transient preparation would result in selective response preparation elicited by the precues A1 and A2 in advance of X and Y, observed as a significant LRP in the cue-probe interval. Finally, the LRP to Y in AY sequences, and to X in BX sequences was used to investigate possible mechanisms responsible for false alarm responses in the CPT.

Method

Participants

Sixteen healthy volunteers who were paid for their cooperation (6 female, 10 male, mean age 24.06, age range 20–40, normal or corrected vision, right-handed) participated in the experiment.

Stimuli

In every CPT variant the stimuli consisted of three sets of consonant letters (C, Q, G, D), (N, H, M, W), (I, L, J, T) (Arial font). From previous studies we know that these letters are easy to discriminate between sets and more difficult to discriminate within a set (e.g., Smid, Lamain, Hogeboom, Mulder & Mulder, 1991). Two letters from one set served as target letters X1 and X2 demanding to respond in the CPT-X and CPT-AX. In the CPT-AX, one letter from the second set served as the cue A, demanding to direct attention to and prepare for a subsequent target stimulus. In the CPT-AcX, two letters from the second set served as response-specific cues A1 and A2. These cues not only demanded to direct attention to a subsequent target stimulus, but also to select and prepare the motor response associated with them. All four letters from the third set served as nontarget letters B and Y. To keep the letter shape probabilities equal in the three tasks, one letter of the second set was presented randomly in the CPT-X with the same probability as in the CPT-AX variants, but without its precue demands. The stimuli were presented on a PC-controlled video monitor as white letters on a black background at a viewing distance of 100 cm. At this distance they subtended 1.5° X 1.5° of visual angle.

Procedure

The participants sat in a chair in a sound- and light-attenuated chamber, with their fore-arms lying on a table on which also the response button panel and video monitor were placed. The participants were instructed to keep body posture and hand positions equal in all conditions. The index finger of each hand rested on one of the response buttons of the button panel. The experiment was run in a single session (approximately 2 hrs), consisting of 18 task-blocks, divided over three conditions (six blocks for each of CPT-X, CPT-AX, and CPT-AcX), and each consisting of a randomized sequence of 164 stimulus presentations.

In every task-block, 17% of the stimuli were target stimuli demanding a response. Every CPT condition consisted of three task blocks that differed in that different letters served as cues, targets and nontargets, so that the letters from each letter set once served as targets, once as cues, and once as non-targets. This ensured that the SN in the ERP can not be attributed to the physical differences between stimuli but to their task-relevance. Each of these three task blocks was run twice.

The order of the three CPT tasks and that of the blocks with different target letters was counterbalanced between participants. Each of the AX (.34), BX (.22), AY (.22) and BY (.22) sequences was presented with the same probability in all three CPT conditions. The stimuli were presented for 150 ms. The inter-stimulus interval, measured from one stimulus onset to the next, was 1300 ms.

The experiment started with an instruction. The participants were first shown the relevant letters for the upcoming block on the video screen for ten seconds (for example, G and Q in the CPT-X, and G, Q and H in the CPT-AX and CPTAcX). They were told that these letters would occasionally be presented randomly in a sequence of other letters. With regard to the CPT-X they were told that one of the letters shown demanded a left-hand button press (X1) and that the other demanded a right-hand button press (X2). They were further told that it was their task to press one of the buttons as fast and accurately as possible when X1 or X2 was presented and to refrain from responding if it was another letter. With regard to the CPT-AX they were told that the letters X1 and X2 demanded a fast and accurate response, but only if preceded by cue A. They were told that X1 demanded a left-hand button press and that X2 demanded a right-hand button pres and to refrain from responding to any other letter. With regard to the CPT-AcX they were told that presentation of X demanded a fast but acurate response, but only if it was preceded by A1 or A2. They were told that A1 indicated a left-hand button press to a subsequent X, and that A2 indicated a right-hand button press to a subsequent X. In every CPT condition, the participants then performed short training blocks until performance had stabilized. Immediately following the last trial of a block, the participant received automated feedback about RTs and error rates on the video screen. The participants were finally told to make as little as possible eyemovements and –blinks.

Recording and Analysis

The ERPs were recorded from the scalp using silver-chloride electrodes located at the scalp sites F7, Fz, F8, C3, Cz, C4, Pz, TO1 (halfway between O1 and the midpoint of a line between P3 and T5) and TO2 (halfway between O2 and the midpoint of a line between P4 and T6). These electrodes were referenced to the left ear lobe. The F3, Fz, F4, C3, Cz, C4, Pz, O1, O2, T5 and T6 sites are defined by the International 10–20 system. The C3 and C4 sites lie over primary motor cortex, and the temporo-occipital TO1 and TO2 sites over cortical areas involved in visual selective attention (Heinze et al., 1994; Smid et al., 1999). Eyeblinks and -movements were monitored with electrodes at both outer canthi of the eyes (horizontal Electro-oculogram (EOG) and above and below the right eye (vertical EOG).

The EEG signals were filtered with a bandpass of 0.01–70 Hz (half-amplitude cutoffs). All signals were digitized at a rate of 512 Hz. Automated artifact rejection on the EEG signals was performed off-line to eliminate data epochs contaminated by EEG artifacts, excessive muscle activity (with a criterion of 100 μV) and amplifier saturation (about 10% of all trials). The influence of horizontal and vertical eyemovements (saccades and blinks) on the EEG recording was corrected using the Gratton and Coles technique (Gratton, Coles & Donchin, 1983).

In case of stimulus-locked averaging, the EEG signals were averaged, separately for each stimulus type (for the X and Y stimuli in the CPT-X, for the cues A and B in the CPT-AX and CPT-AcX, and for X after A, X after B, Y after A and Y after B) in each CPT condition, over epochs of 1400 ms, starting 100 ms before onset of the stimulus and ending 1300 ms post-stimulus, correcting for differences in the 100 ms pre-stimulus baseline. Next, these averages were used for statistical analyses (T-Tests, MANOVA).

To derive the LRP, we first averaged the C3 and C4 ERPs, separately for each participant and condition, on trials on which stimulus information was associated with a left hand response (target X1 the in CPT-X and CPT-AX, and cue A1 in CPT-AcX) and on trials on which stimulus information was associated with a right hand response (target X2 in CPT-X and CPT-AX, and cue A2 in CPT-AcX). Next, we subtracted the averaged C4 ERP from the averaged C3 ERP in each of these classes of trials. Finally, we subtracted the C3-C4 averages on right hand trials from those on left hand trials. In this way we obtained LRPs for the X1 and X2 targets demanding a response in the CPT-X and CPT-AX, for the A1 and A2 cues in the CPT-AcX, and for the X target after an A1 or A2 cue in the CPT-AcX task. This conforms to the formula: ERP(c3-c4)LH – ERP(c3-c4)RH, where c3 and c4 are electrode positions and LH and RH denote left hand and right hand cue or target trials (de Jong, Wierda, Mulder & Mulder, 1988; Smid, Mulder & Mulder, 1987).

Stimulus-locked LRP's were obtained by averaging trials synchronized to stimulus onset. Next we computed the latency at which LRP amplitude had reached 50% of its maximum amplitude ("halfmax latency"; Mordkoff & Giannaros, 2000; Smulders, Kenemans, & Kok, 1996), separately for every participant and condition. We did this in the CPT-X and CPT-AX for the X1 and X2 stimuli and in the CPT-AcX after the target X following one of the A1 or A2 cues. As a convergent control procedure, we also ran a series of t-tests on the LRP amplitudes in a number of consecutive 25 ms epochs, determined by stimulus onset and halfmax latency plus four epochs. For example, in the CPT-X the stimulus-locked halfmax latency of the LRP was 340 ms. We then ran 18 t-tests, that is on18 25 ms epochs, starting at stimulus onset and ending at 450 ms. We did this as a control on the halfmax procedure. If both procedures yielded the same result, we can be confident that the onset of the LRP was correctly estimated. In the other tasks the number of t-tests needed were smaller. The amplitude of the LRP to the A1 and A2 cues in the CPT-AcX was tested by running t-tests on the final 20 25 ms epochs (i.e., 500 ms) of the foreperiod.

The same methods were used to estimate response-locked LRP onset. We determined the halfmax onset latency of the LRP preceding the button press and then ran 10 t-tests at maximum, covering the interval of halfmax latency minus four epochs until the button press latency. For each CPT condition and participant we separately determined onset latency and peak amplitude of the LRP. See Smid et al. (1999) for details of statistical handling multiple epoch testing. Note, however, that the multiple t-test procedure was only used as a control procedure on the half-max method.

To obtain the SN, we subtracted the ERPs elicited by nontargets Y from the ERPs elicited by targets X at electrode site TO1 in the CPT-X and CPT-AX. We first determined the peak latency of the SN difference potentials in the average for every participant and condition by an automated algorithm that recorded peak amplitude and latency in a prespecified window between 125 ms and 300 ms. We next determined the mean voltage of the ERPs to the to-be-attended and the to-be-ignored stimuli in the 20 ms interval enveloping the recorded peak latency of their difference potential. We next tested the null hypothesis that these ERPs were equal. If this hypothesis had a significantly low probability to be acceptable, we accepted the alternative hypothesis that a SN was present. Finally we ran

multivariate ANOVA to determine the effects of task and cuing on amplitude and latency of the significant SNs.

To determine whether there were differences in late CNV amplitude elicited by the cues A and B in the CPT-AX and CPT-AcX we measured the late CNV amplitude at the Cz electrode site in the interval 1150–1250 ms after cue presentation. Next, we ran a multivariate ANOVA with the factors cue relevance and CPT task version.

All analyses were performed with GLM Repeated Measures multivariate ANOVA.

Results

Behavioral Measures

The upper panel of Figure 1 shows that mean RT in the CPT-X was slowest, in the CPT-AX it was intermediate and in the CPT-AcX it was fastest. This main effect of CPT version was highly significant ($F_{1,15} = 115.40$, $p < .0005$) and confirms our prediction that the CPT-AX engages transient response preparation. The lower panel of Figure 1 depicts the mean number of the different types of errors. The number of omission errors was larger in the CPT-AX than in the CPT-X ($F(1,15) = 9.92$, $p < .007$) and not different in the CPT-AX and CPT-AcX ($F(1,15) = 2.76$, $p = .12$), consistent with the prediction that transient attention in the CPT-AX leads to worse target detection performance than sustained attention in the CPT-X. The error type with the highest frequency in the CPT-X and CPT-AX consisted of the response-side errors. These errors consisted of making a button press with the hand opposite to the hand demanded by the X stimulus and are due to the difficulty of letter discrimination, response choice or both. False alarm errors were most frequent in the CPT-AcX (relative to CPT-X: $F_{1,15} = 4.74$, $p < .046$; relative to CPT-AX: $F_{1,15} = 4.68$, $p < .047$). These false alarms were specifically made to the Y stimulus after the cue A, not to the X after cue B. A multivariate ANOVA with the factors task (CPT-AX and CPT-AcX) and stimulus sequence (AY and BX) confirmed this. False alarms were made more often in the CPT-AcX than in the CPT-AX ($F_{1,15} = 5.71$, $p < .030$), and this effect depended on the higher number of false alarms to the AY sequence than to the BX sequence (task by sequence interaction: $F_{1,15} = 5.65$, $p < .031$). These findings suggest that, in healthy people, false alarms are predominantly the result of advance response preparation on the basis of the cue, and less so the result of failing to inhibit the response to an unexpected target. We study this issue further below with the LRP.

Electrophysiological Measures

Processing of the A and B Cue Stimuli

CNV and LRP to the Cues. Figure 2 shows the ERPs that developed in response to the cues A (thick waveforms) and B (thin waveforms) in the CPT-AX and CPT-AcX tasks. In response to the cues A clear late CNVs developed. These concern the large negativities at the midline and central electrodes (thick waveforms) that started after the P300 at about 500 ms. Note, that the ERP to the B cues (thin waveforms) did not contain a CNV. As usual, the late CNVs were largest at the Cz electrode site. We tested the CNVs by averaging the amplitudes in the 1150–1250 ms interval after cue presentation, separately for each of the two types of cue and the two tasks. The cues A produced significantly more negativity than the B cues ($F_{1,15} = 86.488$, $p < .0005$) and this effect was larger in the CPT-AcX than in the CPT-AX (task by cue interaction: $F_{1,15} = 16.705$, $p < .001$). Since CNV amplitude is associated with response preparation, it has been found to be related to response speed (Brunia et al., 1985).
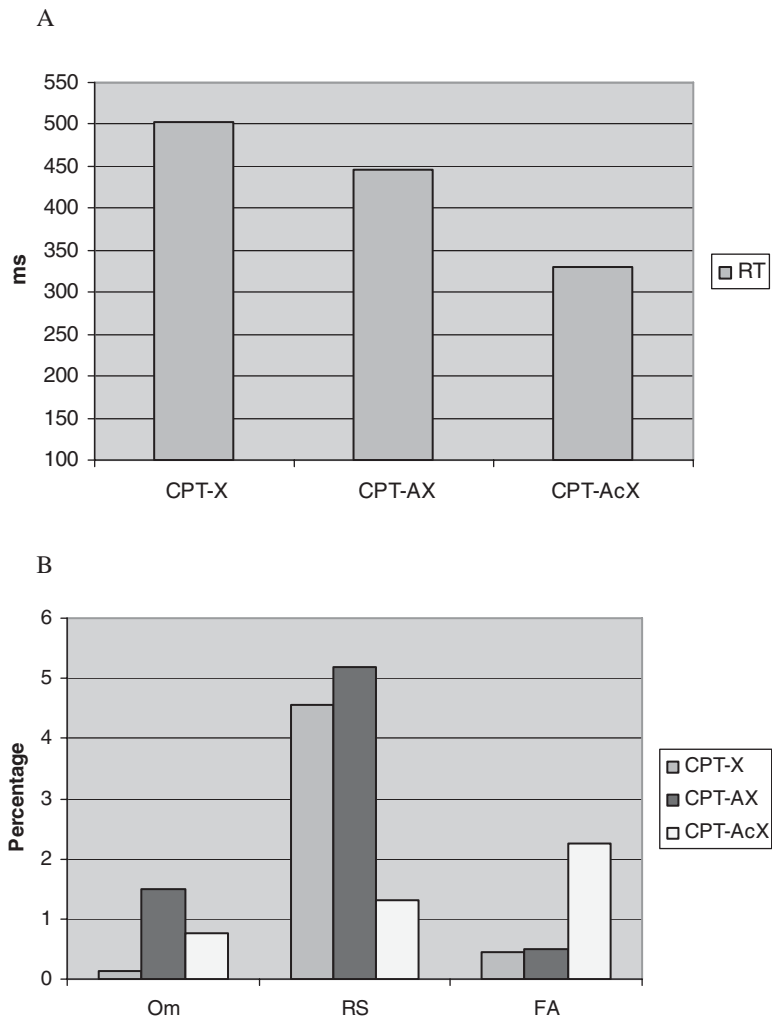
A

B

Figure 1. Averaged mean reaction times to targets (upper panel) and error frequency (lower panel) in the three different CPT conditions.

To confirm whether this was also the case in the CPTs, we performed bivariate non-parametric correlations on CNV amplitude and RT. In both the CPT-AX and CPT-AcX, RT was strongly correlated with CNV amplitude (rho = .756, p = .001 and rho = .682, p = .004, respectively). Thus, fast RTs were preceeded by larger (more negative) CNV amplitude.

Figure 3 shows the foreperiod LRP to the A1 and A2 cues in the CPT-AcX condition (thick continuous waveform). Recall, that A1 and A2 gave the opportunity to prepare selectively the left- or right-hand response in advance of the next stimulus (X or Y). Note, that at about 750 ms after cue presentation (time zero) this waveform deflects downward (positive amplitude). We tested this LRP with 2-tailed t-tests for amplitudes that differed significantly from zero in 25 ms intervals. From 925 ms after cue onset until the presentation of the next X or Y stimulus, the amplitude of this waveform differed significantly from zero (ts15 = 2.25–3.43, ps = .040–.004) in 14 consecutive intervals (350 ms). This shows that a significant
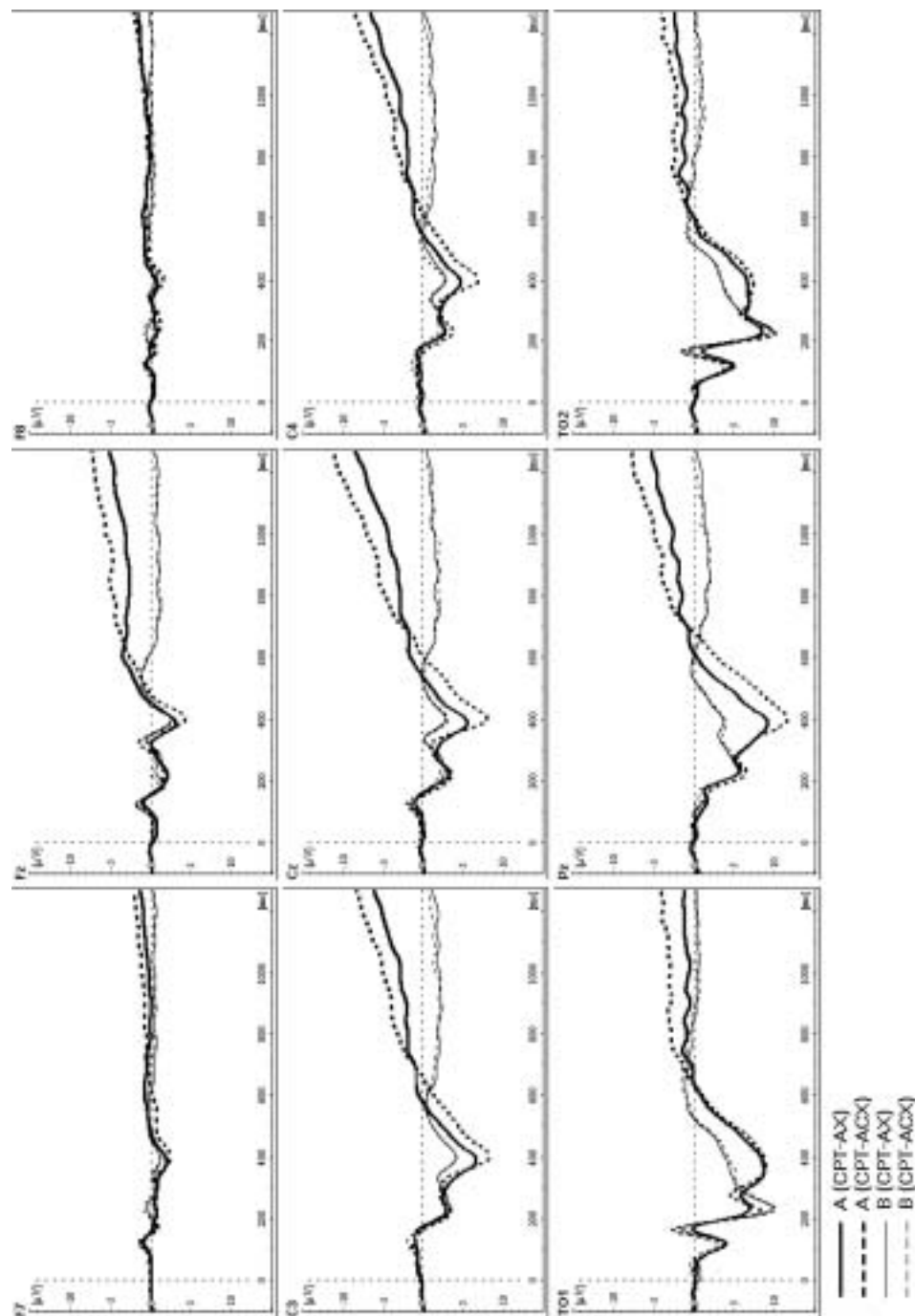
Figure 2. The grand averaged ERPs obtained to the cues A (thick waveforms) and B (thin waveforms) in the CPT-AX (continuous waveforms) and those in the CPT-AcX tasks (dashed waveforms). Electrode positions are indicated in the left-upper corner of each panel.
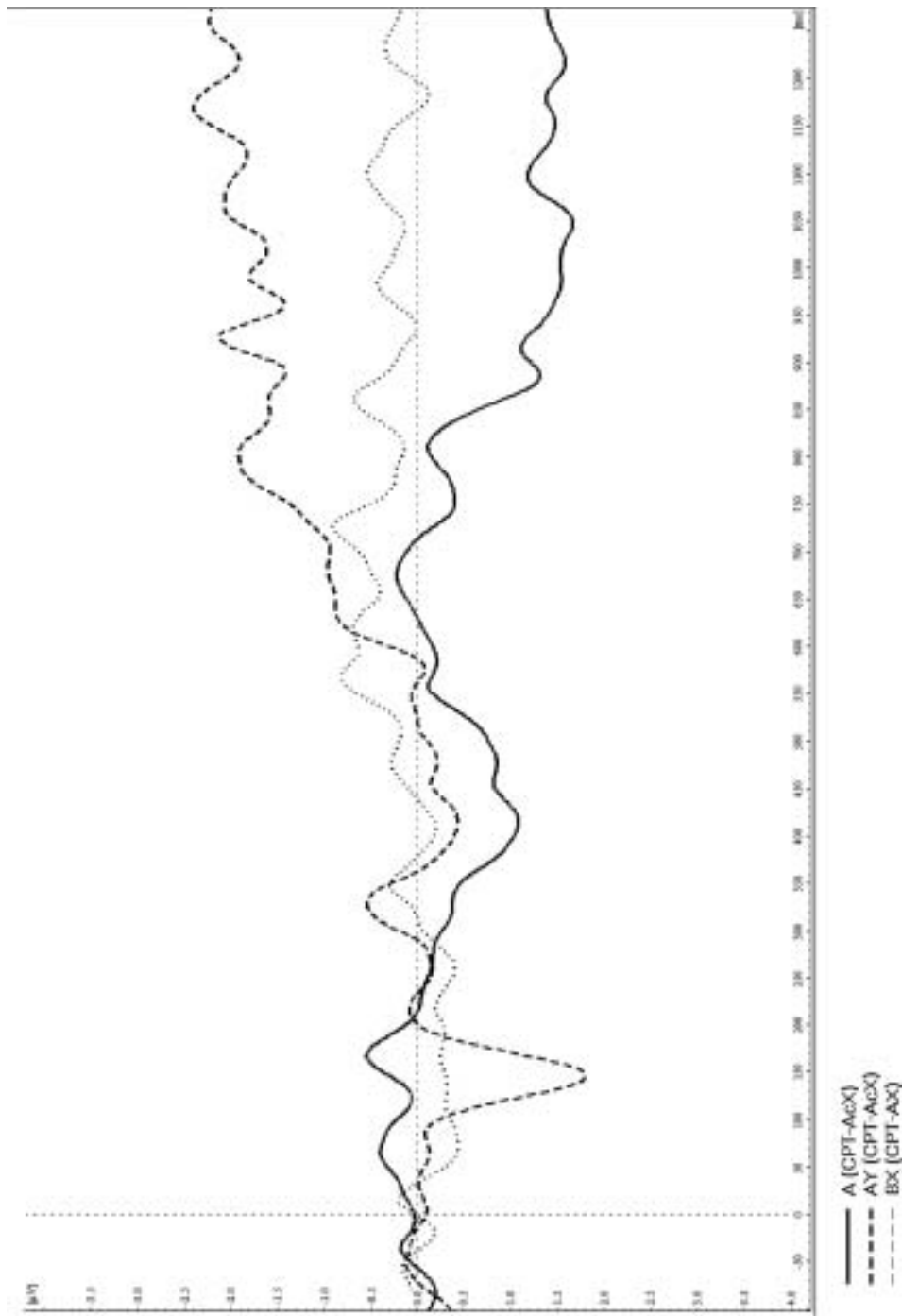
Figure 3. The LRP to the cues A1 and A2 in the CPT-AcX condition (continuous waveform), to nontargetsY preceded by A1 and A2 cues in the CPT-AcX condition (thick dashed waveform), and to targets X1 and X2 preceded by B cues in the CPT-AX condition (thin dashed waveform). See Method for electrode positions. Note:: in the continuous waveform time zero represents presentation of the cue, in the thick dashed waveform time zero represents presentation of the cued nontarget Y, and in the thin dashed waveform time zero represents presentation of the non-cued target X.

LRP was present from 925 ms after the cue until presentation of the next stimulus and is consistent with similar findings in other precuing studies (Leuthold et al., 1996). Figure 3 also shows two other LRPs produced by the non-cued targets (X following B) and cued nontargets (Y following A), but these will be discussed below.

Processing of the X and Y Stimuli

The SN to the X and Y Stimuli. The SN is a difference in the ERPs that is the result of the differential processing of to-be-attended (target X) and to-be-ignored stimuli (nontarget Y). We derived the SN in the CPT-X by subtracting the ERP to non-targets Y from the ERP to the targets X. In the CPT-AX we derived the SN by subtracting the ERP to non-targets Y preceded by cue A, from the ERP to X preceded by A (i.e., ERP[AX – AY]), and by subtracting the ERP to Y preceded by B, from the ERP to X preceded by B (i.e., ERP[BX – BY]).

Figure 4 shows the results of these subtractions. The SNs concern the negative deflections in the ERPs peaking around 200 ms (time zero represents presentation of a target X or nontarget Y). As usual the SN was largest over the left temporo-occipital scalp (electrode position TO1; see Smid et al., 1999), and was 2 µv or more in every waveform. We first tested whether these difference potentials were significantly diffferent from zero amplitude. In the CPT-X, targets produced a significant SN relative to the non-targets (the dashed waveform; $F(1,15) = 38.48$, $p < .0005$). In the CPT-AX, the targets following cue A also produced a significant SN (the continuous waveform; $F(1,15) = 13.95$, $p < .002$) as did those following cue B (the dotted waveform; $F(1,15) = 31.80$, $p < .0005$). We next tested whether the SN amplitudes and latencies were different in the CPT variants and whether they were different due to advance cuing.

As Figure 4 suggests, the SN in the CPT-AX (continuous waveform, i.e., the ERP[AX-AY]) started later and was smaller than the SN in the CPT-X (dashed waveform; $F(1,15) = 8.13$, $p < .012$). This is consistent with earlier findings (Eimer, 1997) and supports our hypothesis that transient attention dominates in the CPT-AX. Figure 4 also shows that in the CPT-AX the SN to the non-cued stimuli (i.e., the ERP[BX – BY] dotted waveform) had the same amplitude as the SN to the cued stimuli (i.e., the ERP[AX – AY] continuous waveform; $F(1,15) < 1$), but was 40 ms later than in the cued ERP[AX – AY] ($F1,15 = 8.75$, $p < .01$). In summary, in the CPT-AX the SN to cued and to non-cued targets was later and smaller than in the CPT-X. Non-cued targets produced a significant but delayed SN.

Lateralized Readiness Potential (LRP) to X and Y. Figure 5 shows the stimulus-locked LRPs (upper panel) and the response-locked LRPs (lower panel) to the target stimuli in the three CPT variants. The LRP started latest in the CPT-X (continuous waveform), intermediate in the CPT-AX (dashed waveform), and earliest in the CPT-AcX (dotted waveform). This was confirmed by the halfmax procedure and the multiple t-test procedure. The halfmax onset latency in the CPT-X (339 ms) was significantly larger than in the CPT-AX (275 ms; $F(1,15) = 20.99$, $p < .0005$), and in the CPT-AX it was larger than in the CPT-AcX (171 ms; $F(1,15) = 35.78$, $p < .0005$). The muliple t-tests procedure yielded consistent results. According to this procedure, the LRP started at 200 ms in the CPT-X ($t15 = 2.27–7.48$, $p = .038–.0005$), at 175 ms in the CPT-AX ($t15 = 4.05–10.3$, $p = .001–.0005$), and at 125 ms in the CPT-AcX ($t15 = 3.59–7.15$, $p = .003–.0005$).

The LRPs synchronized to the button press to the targets in the three CPT tasks showed a different pattern than the stimulus-locked LRPs. The response-locked LRP
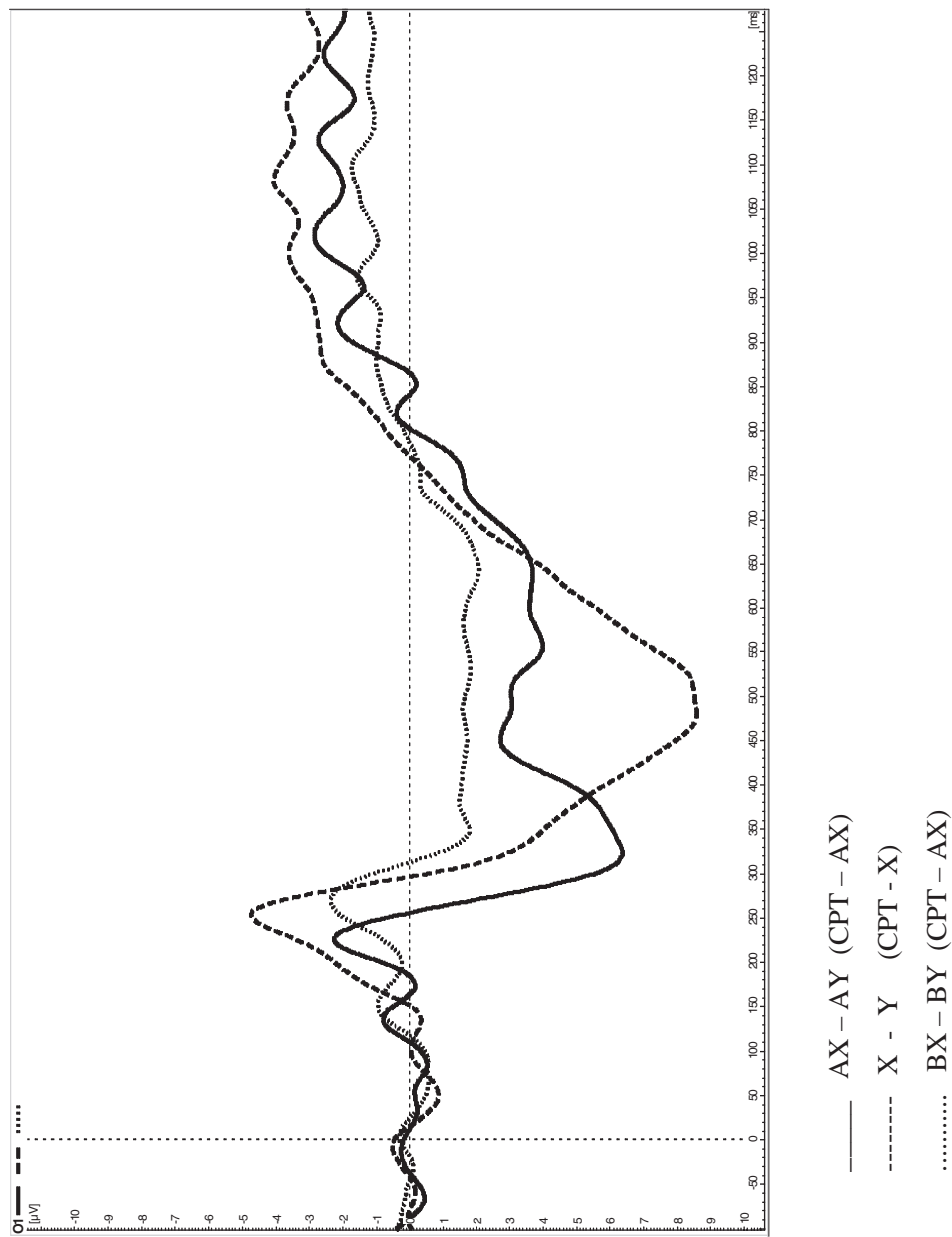
Figure 4. The grand averaged SN obtained at electrode position TO1 to targets and nontargets in the CPT-X (dashed waveform), to targets and nontargets after cue A in the CPT-AX (continuous waveform) and to targets and nontargets after cue B in the CPT-AX (dotted waveform).
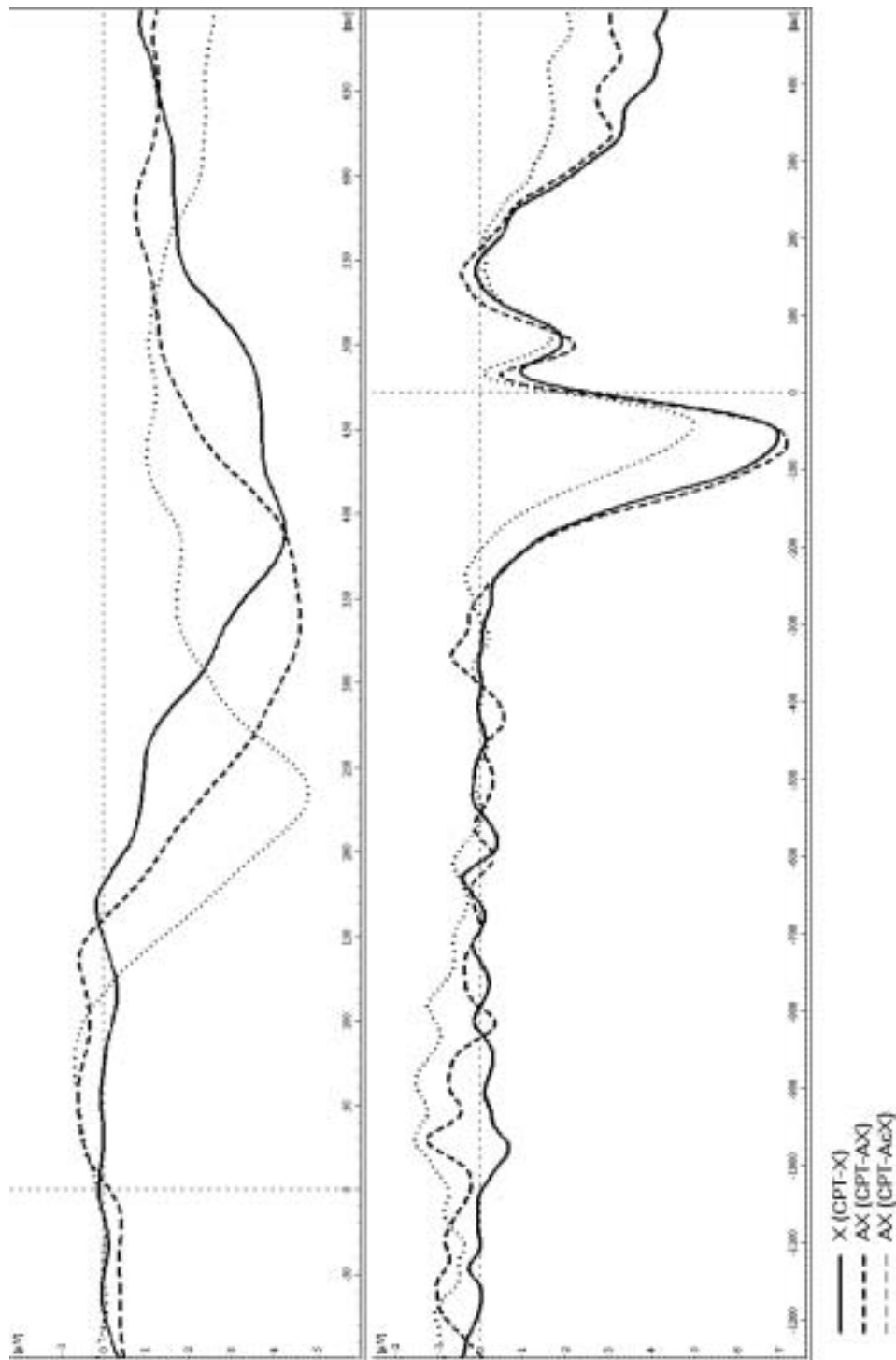
Figure 5. The stimulus-locked LRPs (upper panel) and response-locked LRPs (lower panel) to the targets in the three CPT choice tasks. See Method for electrode positions.

started at about the same time in the CPT-X (continuous waveform) and the CPT-AX (dashed waveform), but closer to the button press in the CPT-AcX (dotted waveform). This was confirmed by the halfmax procedure and the multiple t-test procedure. The halfmax onset latency in the CPT-X (−139 ms) was not different from that in the CPT-AX (−145 ms; $F(1,15) = 1$), and in the CPT-AX it was larger than in the CPT-AcX (−117 ms; $F(1,15) = 11.17$, $p < .004$). The muliple t-tests procedure yielded consistent results. According to this procedure, the LRP started at −175 ms in the CPT-X (from first significant epoch until button press: $t15 = 2.71$–9.75, $p = .016$–$.0005$), also at −175 ms in the CPT-AX ($t15 = 2.49$–7.87, $p = .025$–$.0005$), and at −150 ms in the CPT-AcX ($t15 = 2.59$–7.90, $p = .021$–$.0005$).

In summary, in the CPT-AX the stimulus-locked LRP started earlier than in the CPT-X and the response-locked LRP started at the same time and had the same amplitude in both tasks. These findings indicate that the faster RTs and earlier stimulus-locked LRPs in the CPT-AX are the result of earlier finishing pre-motor processes and not due to earlier finishing motor processes.

So far we have analyzed the LRPs accompanying correct responses to the targets in the AX sequences. To investigate false alarm errors, we also analyzed the LRPs to the nontargets Y in the AY sequences of the CPT-AcX and to the targets X in the BX sequences of the CPT-AX. If in the CPT-AcX the motor response is prepared on the basis of the cue (A1 or A2), presentation of any stimulus may lead to a further increase in motor preparation, sometimes resulting in a false alarm button press. In the same manner, if in the CPT-AX target X1 or X2 is presented unexpectedly, it may lead to automatic motor activation of its associated response, resulting in a LRP, and possibly a false alarm. For the analysis of the AY LRP, we separately averaged the ERPs to nontargets Y preceded by A1 cues and the ERPs to nontargets Y preceded by A2 cues. For the BX LRP analysis, we separately averaged the ERPs to targets X1 and X2 preceded by cues B in the CPT-AX. Figure 3 shows the results of these analyses. To understand this figure it is important to realize that time zero in the figure represents different events. Thus, in the continuous waveform time zero represents presentation of the cue A in the CPT-AcX (see above "CNV and LRP to the cues"). In the thick dashed waveform time zero represents presentation of the nontarget Y in the CPT-AcX and in the thin dashed waveform it represents presentation of the target X in the CPT-AX.

There was a LRP (nearly 2 μvolts) evoked by the nontargets Y when preceded by cue A in the CPT-AcX, peaking at 150 ms (see the thick dashed waveform). This LRP was highly significant from 125 until 175 ms ($t15 = 3.0$–5.54, $p = .009$–$.0005$). Note, that this LRP slowly develops in negative direction (i.e., upward) after about 600 ms. This indicates that this LRP returned to baseline level after having been deflected in positive direction (downward) due to advance preparation in the interval between cue A and the target. Recall, that this advance preparation to the cue A is represented by the thick continuous waveform (see above "CNV and LRP to the cues"). Note, that the positive deflection in the Y-target waveform mirrors in amplitude the negative deflection in the A-cue waveform. There was no LRP to the target following a cue B in the CPT-AX (the thin dashed waveform).

Discussion

To date, no study has directly compared performance and ERP measures from different CPT versions in healthy participants to identify what the CPT really measures. We proposed that different CPT versions can be categorized along the task variables sustained

versus transient attention and sustained response preparation versus transient response preparation. On the basis of this classification we proposed that the CPT-X is a sustained attention—sustained response preparation task and that the CPT-AX is a transient attention—transient response preparation task. Previous research shows that transient attention leads to worse target detection than sustained attention and that transient preparation leads to faster task performance than sustained preparation. On the basis of our classification we therefore predicted that (1) measures of target detection would show worse target detection in the CPT-AX than in the CPT-X and (2) measures of pre-motor and motor processing would show faster task performance in the CPT-AX than in the CPT-X. To investigate these predictions we applied behavioral measures and ERPs that are selectively sensitive to target detection and response preparatory activity in three different CPT tasks.

The behavioral and ERP findings confirmed our predictions. In the CPT-X omissions were less frequent than in the CPT-AX, indicating that target detection performance was better in the CPT-X, consistent with previous findings in patients by Borgaro et al. (2003). In addition we found that the SN had a significantly larger amplitude in the CPT-X than in the CPT-AX, also consistent with earlier findings (Eimer 1997). Since the amplitude of the SN can be assumed to reflect the extent of visual selective processing (Eimer, 1997; Smid et al., 1999), the present findings support the hypothesis that better target detection performance in the CPT-X is related to enhanced visual selective processing of the target at an early stage of processing (150–200 ms).

In contrast to the decrease in target detection performance in the CPT-AX stands the increase in performance speed in that task. The RTs were shorter and the stimulus-locked LRPs started earlier in the CPT-AX than in the CPT-X. The response-locked LRPs, however, were not different in these tasks. These findings suggest that in response to the target, the pre-motor processes, including response programming, are executed faster in the CPT-AX than in the CPT-X, so that the motor process starts earlier but, once started, takes equally long in the CPT-AX and CPT-X. The faster performance in the CPT-AX was not accompanied by more false alarms, ruling out a speed-accuracy trade-off as an alternative explanation.

We predicted these findings because in the CPT-AX response preparation is transiently varied according to the demands of the cues and because transient response preparation is known to produce faster task performance (cf., Leuthold et al., 1996). The CNV findings support this interpretation. In response to the cue A in the CPT-AX a CNV developed, which was absent in response to the cue B, consistent with earlier findings (van Leeuwen et al., 1998). Furthermore, the amplitude of the CNV was positively correlated with reaction speed. This supports the hypothesis that CNV amplitude is related to response programming in advance of the cued stimulus (Ulrich et al., 1998). The effect of advance response programming is that less programming needs to be done in response to the cued target, resulting in an earlier start of the stimulus-locked LRP and faster RTs. The CNV findings therefore show that in the CPT-AX the participants only prepared to process a target in response to cue A and not in response to cue B, and that this transient preparation resulted in faster LRP and button press responses to the target. In the CPT-X this flexibility in the control of preparatory activity is not possible because every stimulus can be a target so that preparation must be sustained (but at a low level) during the entire task.

Together the present performance and ERP findings directly support our hypothesis that the CPT-X is a sustained attention—sustained response preparation task and that the CPT-AX is a transient attention—transient response preparation task. They further show that in the CPT-AX transient attention leads to impoverished target detection and transient preparation leads to increased speed of performance. Impoverished target detection seems

related to an early perceptual process (150–200 ms after target presentation), with a posterior parietal source and reflected in a smaller SN. The increase in performance speed seems related to advance response selection and programming, resulting in earlier but not shorter motor preparation after target presentation.

Since the present findings are from CPT variants in which we inserted response choice between hands, one may ask whether these conclusions can be generalized to CPT variants without response choice. For example, transient preparatory activity on the basis of cue A in a traditional CPT-AX in which only a single overt response needs to be prepared may be different than in the present CPT-AX in which two responses need to be prepared. First, the existing literature shows that increasing the number of motor response alternatives slows down motor preparation after target presentation but does not influence the other cognitive functions engaged in the task (Donders, 1969; Hackley et al., 1990; Smid et al., 2000). Secondly, findings from two other studies that applied CPTs not requiring choice between response hands with patients and healthy participants yielded comparable performance results as the present study, that is, more omissions and faster RTs (although not statistically tested or discussed, Dias et al., 2003; Kaskey et al., 1980) in the CPT-AX compared to the CPT-X.

To be sure, we ran a control experiment before the present study was carried out, in which behavioral performance in the present three tasks was compared with performance of the traditional single-response versions of the CPT-X and CPT-AX. The results showed that type of task and response choice had additive effects on RTs and error frequency, that is, adding response choice to the tasks increased RTs to the same amount in both CPTs. According to the additive factors logic (Sternberg, 1969) this indicates that adding the process of response choice to the CPTs prolonged the time needed for motor preparation in response to the targets, but did not influence the other processes engaged in the tasks. Furthermore, the performance of the CPT-AcX was indistinguishable from the performance of the single-response CPT-AX, so that the CPT-AcX can be taken to be equivalent to the single response CPT-AX with regard to response choice mechanisms. Moreover, in the present experiment response locked LRP onset latency was closer to the button press in the CPT-AcX than in the other two CPTs, indicating that motor preparation took less time in that task. Based on these arguments we conclude that the present findings can be generalized to single-response CPTs.

A second issue concerned the source of false alarm errors in the CPTs. In many studies it has been assumed that the frequency of false alarm errors is associated with a failure of response inhibition or impulsivity (cf. Borgaro et al., 2003; Riccio et al., 2002). The focus of previous studies has been on false alarms in the CPT-AX because they are more frequent than in the CPT-X and may be related to partial and unfinished evaluation of the stimulus. Premature responding to partial information is a common cause of false alarm errors (Smid, Mulder & Mulder, Brands,1992). Some studies have therefore focused on false alarm frequency to the target X preceded by cue B (e.g., Elvevag et al., 2000) and others on false alarm frequency to a non-target preceded by cue A (e.g., van Leeuwen et al., 1998). To shed light on this issue, we compared false alarm frequency and associated ERPs in the BX and AY sequences of the CPT-AX and CPT-AcX. Especially the results in the CPT-AcX are important for this issue, because this task is equivalent to the traditional single-response CPT-AX.

We found that false alarm frequency was highest in the CPT-AcX, and not different in the other CPTs. Recall, that in the CPT-AcX the choice between a left or right hand response was made on the basis of the cue A and in advance of the target. The majority of the false alarms were made to the nontargets after the cue A, not to the targets after cue B.

There was an early LRP evoked by the nontargets after cue A in the CPT-AcX, but no LRP to targets after B in the CPT-AX. This suggests that the nontargets produced motor preparation of the hand prepared on the basis of cue A, and that the targets did not produce motor preparation of their associated hand after cue B. There was a foreperiod LRP after the A1 and A2 cues in the CPT-AcX, showing that the LRP to the nontargets was indeed preceded by advance selective motor preparation. These findings indicate that there was a response tendency to nontargets after cue A, but not to targets after cue B. Further, the latency of the SN to targets in the ERP[BX – BY] was 40 ms later than to the targets in the ERP[AX – AY]. This finding suggests that detection of the target was delayed when it was not prepared on the basis of a precue, making fast false alarms improbable. Thus, in normal people false alarms in the CPT-AX are predominantly due to the transient preparatory activity induced by the cue A and not to a habitual response tendency to the target X. The absence of a response tendency to uncued targets could be the result of the late detection of these targets, but may be specific to the normal population.

Although the present findings neatly confirmed the predictions on the basis of the sustained – transient task dimensions, they seem inconsistent with previous findings obtained in the sustained and transient attention tasks that Eimer (1997) applied and those obtained in the CPT-Identical Pairs version. Although Eimer found a smaller SN and a higher frequency of omissions in the transient than in the sustained attention task, the RTs were slower and false alarms were more frequent in the transient condition. When findings obtained in the sustained attention CPT-X and transient attention CPT-Identical Pairs tasks are compared, omission error frequency is higher and RTs are slower in the latter task (Dias et al., 2003; Strandburg et al., 1999).

This can be explained when considering the sustained – transient response preparation dimension. On the basis of our classification in two task dimensions, we proposed that the CPT-Identical Pairs is a transient attention – sustained response preparation task, because the letter to attend depends on the cue and because all cues call for advance response preparation. The same is true for the tasks used in the study by Eimer (1997). In that study, the sustained attention task required that the participants attended the same stimulus during the entire task. The transient attention task consisted of cue – probe sequences, in which every cue signaled a potential target requiring a response and therefore every cue called for advance response preparation. The feature that distinguishes transient attention – transient preparation tasks from transient attention – sustained preparation tasks is that in the former there are two types of cues, cue A signaling to attend and prepare for a target and cue B signaling to attend to cue A only and not to prepare for a response. In transient attention – sustained preparation tasks there are several cues of type A (e.g., A1 – attend/respond to green, and A2 – attend/respond to red), but no cue of type B. For example, in the CPT-Identical Pairs every previous stimulus demands to prepare for a potential target, albeit of different identity. Since sustained preparation leads to slower task performance than transient preparation, and transient attention leads to worse target detection than sustained attention, transient attention – sustained preparation tasks produce the worst overall performance of the three types of tasks considered here.

Several alternative explanations are possible. First, one may argue that in the Identical Pairs and CPT-AX memory load is higher than in the CPT-X because only in those tasks every previous stimulus must be maintained in working memory, but not in the CPT-X (cf. Strandburg et al., 1999). Apart from the response preparation dimension, this could explain the difference in target detection between the CPT-AX (and Identical pairs) and the CPT-X. There is, however, no clear reason that working memory load is less in the CPT-X. In all

three tasks the instructed stimulus must be attended in advance of every stimulus, whether the attended stimulus is instructed verbally (CPT-X) or by a previous stimulus. What is clearly different between these three tasks is the size of the set of stimuli among which attention has to switch. This set is smallest in the CPT-X, intermediate in the CPT-AX and largest in the CPT-Identical pairs (in fact the entire stimulus set used). We therefore believe that in all three tasks maintenance in working memory is about equally important, but that the cognitive function of having to switch between what is maintained in working memory is critical for differences in target detection performance in these tasks.

A second alternative explanation may be that target detection in the CPT-AX is worse than in the CPT-X because in the CPT-AX more controlled processing is needed than in the CPT-X (cf. Stranburg et al., 1999). In this view, the CPT-X is a consistent mapping task and the CPT-AX a varied mapping task (Shiffrin & Schneider, 1977). We think this is not an alternative explanation but a more general one. We think that having to switch attention is a specific type of controlled processing and that the concept of transient orienting of attention more specifically identifies the cognitive process involved than the rather global concept of controlled processing.

With regard to the sample size we used, readers familiar with much larger sample sizes might be concerned about the generalizability of the present effects. First, it is generally accepted that in ERP research a sample size of 12 or more subjects is used. One criterion for a large enough sample size is the statistical power of the tests. The observed power of the ERP effects in the present study (but also in many other ERP studies with limited sample size) is high. The observed power of the SN and LRP effects in this study (of target versus nontarget, of task) typically were higher than .90 and very often simply 1.0. Furthermore, most of the effects found in the present study replicate earlier findings (see above), indicating good generalizability. We are therefore confident that our findings are not restricted because of the relatively small sample size.

In conclusion, the present findings support our two-dimensional view of the critical cognitive functions engaged in different CPTs and can be used to reconcile existing, seemingly opposing, hypotheses. The hypothesis that the critical function concerns the maintenance of context information in working memory (e.g., Cohen & Servan-Schreiber, 1992) and the hypothesis that it concerns response readiness (e.g., Goldberg & Weinberger, 1995), are both partially right. Maintenance in working memory is a critical function for CPT performance, not for the difference in performance of different CPT variants, but for CPT performance in diagnostic groups that have an impairment in that function. Critical for the performance in different CPTs are the demand for transient attention, that is, the extent to which attention has to be switched between different stimuli and the demand for sustained or transient response preparation. Thus, maintenance of information is critical for CPT performance in general, but it is the switching of the information being maintained that is critical for performance differences in different CPTs.

Finally, we discuss the implications of the present findings for the application of the CPTs and their construct validity in clinical studies. First, our findings show that the main CPT variants differ on two task dimensions. Variation on each of these dimensions has strong, sometimes opposite effects on task performance. This conclusion is consistent with that of Borgaro et al. (2003) who concluded on the basis of target detection measures that there is only moderate overlap of the cognitive functions engaged in the main CPT versions. Thus, different CPT versions do not measure the same construct. Our findings throw new light on this conclusion because they show which cognitive functions are differentially engaged in the CPTs. The CPT-X predominantly engages sustained attention and sustained response preparation. The CPT-AX (with low AX probability) predominantly

engages transient attention and transient response preparation. The CPT-Identical pairs predominantly engages transient attention and sustained response preparation. Thus, the CPT-AX and CPT-Identical Pairs are not sustained attention tasks, as is often assumed. Instead they are transient attention tasks that require to switch attention from focusing on one stimulus to focusing on another stimulus. When applying these tasks it is therefore very important to analyze not only target detection measures like d', omission and false alarm frequency, but also RTs. Only then can effects on speed of performance (i.e., on transient preparation) and on target detection (i.e., on transient attention) be differentiated.

The present findings further show that questions like "Do our patients have a sustained attention deficit?", "Does this treatment ameliorate our patient's transient attention deficit?", etc., can not be answered by simply administering one CPT variant and analyze the effect of the independent variables on RT and accuracy, because every CPT variant has a sustained attention component (the instructions). The effect of independent factors on response preparation can also not be determined by using a single CPT variant (for example the CPT-AX), because a change in RT relative to that in controls may be the result of pre-motor processing or even the build-up of peripheral muscle activity. These questions may, however, be answered if two or more variants are applied in a single study. Using two variants, for example the CPT-X and CPT-Identical Pairs makes it possible to isolate and study the transient attention function, while response preparation is held constant. It also opens the possibility of applying the Additive Factors logic (Sternberg, 1969). According to this method, two factors influence different cognitive functions when they have additive effects on RT, whereas they influence the same cognitive function when they interact. Suppose one wants to answer the question whether a patient group has a response preparation deficit. Next, one could ask a patient and a control group to perform the CPT-AX and CPT-Identical pairs tasks. Our current argument suggests that between these tasks response preparation varies, and attention is kept transient. Thus, if the increase in response speed in the CPT-AX relative to that in the CPT-Identical pairs, would be smaller in patients than in controls, it would suggest that patients have a response preparation deficit. We think application of this method could greatly enhance the utility of behavioral studies in determining the cognitive effects of pathologies and treatments.

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