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The relationship between sustained attention, attentional selectivity, and capacity

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The Theory of Visual Attention (TVA; Bundesen, 1990) provides a quantitative account of visual attentional selectivity and capacity but does not include a parameter relating to sustained attention. We conducted two studies to examine the relationship between sustained attention and the TVA parameters relating to selectivity and capacity. In the first study ($n = 46$; mean age $= 41$, $SD = 10$), we investigated the effects of self alerting during a combined whole and partial report task (CombiTVA). In the second study, 70 participants (aged 20–69), performed the CombiTVA and the Sustained Attention to Response Task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The results indicated that attentional selectivity and capacity were unaffected by self alerting, unrelated to sustained attention ability and robust to the adverse effects of time-on-task. These findings are in keeping with the idea of independent functions relating to sustained attention and attentional selectivity and capacity.

Keywords: Attentional ability; Sustained attention; Theory of Visual Attention.

The Theory of Visual Attention (TVA) is a computational theory of visual selective attention and recognition. First proposed by Bundesen (1990), it provides quantitative accounts for a wide range of attentional effects reported in the psychological literature. At the heart of TVA lie two equations which jointly describe two mechanisms of attentional selection: *filtering* (selection of *objects*) and *pigeonholing* (selection of *features*). Bundesen, Habekost, and Kyllingsbæk's Neural Theory of Visual Attention (NTVA; 2005) provided a neurophysiological interpretation of these equations. According to NTVA, filtering changes the number of cortical neurons in which an object is represented while pigeonholing scales the level of activation in neurons coding for a particular feature. By these mechanisms, behaviourally important objects and features are likely to win the *biased competition* (Desimone & Duncan, 1995) to become encoded into visual short-term memory (VSTM). The VSTM system is conceived of as a feedback mechanism that sustains activity in the neurons that have won the attentional competition. NTVA accounts both for a wide range of attentional effects in human performance (reaction times and error rates) and a wide range of effects observed in single cells (firing rates) in the primate visual system (Bundesen & Habekost, 2008; also see Kyllingsbæk, 2006).

TVA has laid the foundation for TVA-based assessment of attentional functions, which has many advantages compared with conventional

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clinical tests of visual attention: Performance is analysed into separate functional components (*specificity*); the method can reveal deficits that go undetected by conventional clinical testing (*sensitivity*); the measurement error can be quantified and in most cases shown to be minor (*reliability*); and the measures that are obtained are not bound to the tasks used, but grounded in a general theory of visual attention (*validity*). In the pioneering study, Duncan et al. (1999) showed how analysis of partial and whole report performance in terms of parameters defined by TVA enabled a very specific measurement of attention deficits in visual neglect patients (see also Bublak et al., 2005; Finke et al., 2005). TVA-based assessment has now been used in studies of simultanagnosia (Duncan et al., 2003), integrative agnosia (Gerlach, Marstrand, Habekost, & Gade, 2005), developmental dyslexia (Dubois et al., 2010), alexia (Habekost & Starrfelt, 2006; Starrfelt, Habekost, & Gerlach, 2010; Starrfelt, Habekost, & Leff, 2009), Huntington's disease (Finke et al., 2007), Alzheimer's disease (Bublak, Redel, & Finke, 2006; Bublak et al., 2009; Redel et al., 2010), and effects of stroke in particular parts of the brain (Habekost & Bundesen, 2003; Habekost & Rostrup, 2006, 2007; Peers et al., 2005; see Habekost & Starrfelt, 2009, for a review). TVA-based assessment enables the estimation of parameters related to attentional capacity and selectivity, namely, span of VSTM (storage capacity of K objects), the rate of encoding into VSTM (processing capacity of C objects/s), the perceptual threshold (minimum effective exposure duration of t_0 ms), and the efficiency of selecting targets rather than distractors (selectivity $\alpha =$ the attentional weight of a distractor divided by the attentional weight of a target).

Although the TVA provides a quantitative account of attentional selectivity and capacity, in its current form, it does not include a parameter relating to sustained attention. Sustained attention refers to the endogenous maintenance of alertness and focus over time (Sturm, 1996) and is thought to rely upon a right frontal-parietal cortical network, which interacts closely with a subcortical arousal system (Robertson & Garavan, 2004). At any given moment, a person's ability to sustain attention will be determined by a dynamic interplay between exogenous factors (such as the saliency of external stimuli) and endogenous factors relating to motivation, cognitive control, and physiological arousal. A person's sustained attention therefore has a natural propensity for fluctuation (Smallwood, Fishman, & Schooler, 2007). It is as yet unclear how the TVA parameters of attentional selectivity and capacity might be influenced by the waxing and waning of sustained attention.

A few studies have investigated this issue. Finke et al. (2010) examined the effects of two psychostimulants, methylphenidate and modafinil, on VSTM storage capacity and visual perceptual processing capacity, as measured in the TVA whole report paradigm. These drugs increase arousal by enhancing the synaptic availability of the two catecholamines, dopamine and noradrenaline. Finke et al. found that both stimulants enhanced visual processing capacity and one stimulant (modafinil) enhanced VSTM capacity but only in those participants with low processing and storage capacity (i.e., below the median score). For those participants whose VSTM and processing capacity were above the median, the psychostimulants had no effect. Matthias et al. (2009) manipulated intrinsic alertness by asking participants to perform a 50-minute vigilance task prior to completing a TVA partial report task. These authors found that lowered alertness had no effect on visual processing capacity or efficiency of top-down attentional selection. Matthias et al. (2010) investigated the effects of phasic alertness by incorporating visual alerting cues into a TVA whole report paradigm. The phasic alerting cues were found to have a very fast but short-lived effect on visual processing capacity (i.e., only at the shortest cue–target interval of 80 ms) and no effect on VSTM storage capacity. Vangkilde, Coull, and Bundesen (2011) investigated the effects of temporal expectation on TVA parameters by varying the interval between cue and target during a TVA paradigm. They found that while perceptual threshold remained unaffected by the manipulation, visual processing capacity was increased by temporal expectancy.

In this paper, we present two studies which examined the relationship between visual attentional selectivity and capacity, assessed by the TVA paradigm, and sustained attention. In the first study we investigated whether a technique designed to enhance sustained attention during a task could enhance visual attentional selectivity and capacity. This technique, which involves periodic endogenous alerts, has been shown to improve sustained attention in stroke patients (Robertson, Tegner, Tham, Lo, & Nimmo-Smith, 1995), normal healthy adults and adults with

ADHD (O'Connell et al., 2008). In the second study, we, first, examined the relationship between the TVA parameters and performance on the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), which is a well-validated measure of sustained attention that has been found to activate the right frontal and parietal areas thought to subserve sustained attention (Manly et al., 2003) and has proved sensitive to sustained attention deficits in clinical populations such as closed head injury (McAvinue, O'Keeffe, McMackin, & Robertson, 2005) and ADHD (Johnson et al., 2007). Second, we investigated time-on-task effects during the CombiTVA paradigm. It is a well-known fact that sustained attention has a tendency to decline with time-on-task. In vigilance tasks, in which participants are required to sit for long periods of time (e.g., over 30 min) to detect infrequent target stimuli, this decline, known as the vigilance decrement, manifests as a reduction in detection rate and an increase in response time for detection during latter periods of the task (Parasuraman, 1984; Parasuraman, Warm, & See, 2000; Warm, 1984). As the CombiTVA paradigm is of similar length (i.e., approx 40 min) to typical vigilance tasks, involving over 300 repetitive trials, and therefore, arguably, requires the endogenous maintenance of attention over time, it seemed an ideal task to examine whether attentional selectivity and capacity parameters were also vulnerable to decline with time-on-task.

STUDY 1: THE EFFECTS OF SELF ALERTING ON VISUAL ATTENTIONAL SELECTIVITY AND CAPACITY

Method

Self Alert Training is a technique involving periodic, endogenous, "self alerts", which serve to sustain attention to task. The effects of self alerting on attentional selectivity and capacity were examined by comparing TVA parameters in an alert group, trained to self alert throughout the CombiTVA paradigm, with two control groups: an active control group trained to relax throughout the task (relax group) and a passive control group that simply performed the task twice (control group).

Participants

Forty-six volunteers, comprising 16 men and 30 women, aged from 24 to 61, mean age $= 40.9$, $SD = 10.3$, were randomly allocated to an alert group ($n = 15$), a relax group ($n = 16$), or a control group ($n = 15$). There was no significant difference between the three groups in terms of age, $F(2, 45) = 1.09$, $p = .35$, sex, $\chi^2(2) = 0.67$, $p = .72$, or education, $\chi^2(4) = 5.22$, $p = .27$. For both studies presented in this paper, participants were recruited through the Psychology Department Participant Panel and poster advertisement within the college. The Psychology Department Participant Panel consists of volunteers from the general public who have expressed an interest in participating in psychological research. The samples described in this paper comprise a mixture of students from the university and members of the general public who vary considerably in terms of background, education, and age. Participants were excluded if they had a history of psychiatric disorder or neurological insult. Participants' near and colour vision were screened using the Revised Sheridan Gardiner Test (Sheridan, 1970) and the Ishihara Test for Colour-Blindness (Ishihara, 1960). Ethical approval was granted by the Psychology Department Ethics Committee and all participants provided informed consent prior to participation.

Materials

CombiTVA paradigm. The CombiTVA paradigm (Vangkilde, Bundesen, & Coull, in press; see Figure 1) involved a brief flash of red and blue letters on computer screen with the participant's task being to report all red letters (targets) but to ignore blue (distractors). The test took approximately 40 min for each participant and included 324 trials arranged into nine blocks. Each trial consisted of the presentation of a red fixation cross (1000 ms), the stimulus display, and a postdisplay mask (500 ms). The participant was instructed to fixate on the red cross and to make an unspeeded verbal report of the red letters he/she saw when the screen went blank, following the mask presentation. The researcher typed the letters as the participant reported them. There were three stimulus display types: whole report of six targets, whole report of two targets, partial report of two targets, and four distractors. The six-target whole report trials were presented for 10, 20, 50, 80, 140, and 200 ms. The two-target whole report trials and the partial report trials were presented for 80 ms. In order to facilitate alerting and relaxing during the TVA paradigm, five cues (a black screen with a yellow border) were presented during each of the nine blocks (i.e., 45 cues during the task). Each cue remained for 10 s. During the first session, participants were instructed to pause during the cue. During the second session, participants in the alert group were instructed to use the cue as a prompt to self alert, participants in the relax group were told to use to cue as a reminder to relax, and participants in the control group were told to pause. TVA modelling procedures (Kyllingsbaek, 2006) were applied to estimate the following parameters for each participant:

- t_0: *Perceptual threshold*—the minimum exposure duration (milliseconds) at which letter identification is better than chance.
- *K: Visual short-term memory (VSTM) capacity*—the maximum number of letters the participant can report.
- *C: Visual processing capacity*—the rate of encoding into VSTM, expressed in terms of letters per second.
- α *(alpha): Efficiency of top-down selection*—a value reflecting the participant's ability to focus on the target letters and ignore distractors. A value of 0 indicates perfect selectivity with higher values indicating poorer selectivity and values of 1 or greater indicating complete nonselectivity on the part of the participant.

Self alert training. The purpose of self alert training is to enhance participants' sustained attention to task by providing them with a mechanism to boost alertness periodically. Self alerting involves three components: a shift in posture, such as a change from a slumped to an upright position; a deep breath; and a self instruction in the form of a personal catchphrase, such as ''pay attention'', ''wake up'', or ''focus'', which the participant silently says to him or herself in order to direct his/her attention to the task at hand. The first two components are designed to provide a boost in physiological arousal and the third is a cognitive tool with a motivational component, used to harness the increase in arousal in order to sustain attention to the task at hand. Biofeedback of skin conductance, a marker of autonomic arousal (Dawson, Schell, & Filion, 2000), is also a central part of the training, enabling participants to see the effects of each self alert on their autonomic arousal.

Self alert training began with psychoeducation about the relationship between skin conductance and alertness and an exposition of self alerting. Participants then engaged in self alert training, alerting, first of all, upon the researcher's instruction (six alerts), and then upon their own instruction (six alerts). Skin conductance biofeedback was used in order to demonstrate the effect of alerting upon physiological arousal. For each self alert, participants were instructed to use the three components (shift in posture, deep breath, self

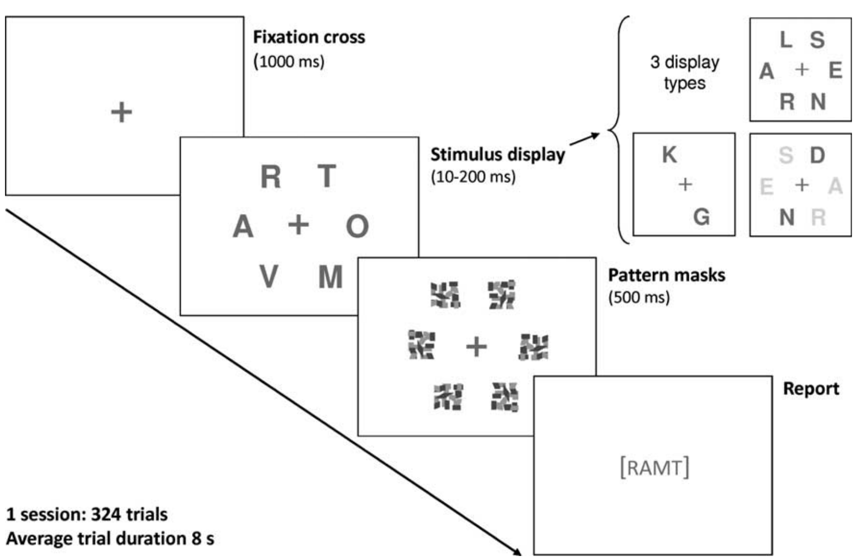

Figure 1. Illustration of the CombiTVA paradigm.

instruction) in order to produce a skin conductance response in their skin conductance trace (see Figure 2a). Three biofeedback screens were used: a basic screen displaying skin conductance level as a red line, a screen displaying a cartoon face, which smiled as skin conductance increased, and a screen displaying a light bulb, which lit up as skin conductance increased.

Relaxation training. Skin conductance biofeedback formed a central part of relaxation training (see Figure 2b). Participants were, first of all, given psychoeducation about the relationship between relaxation and skin conductance. They were then left alone in a darkened room for 15 minutes. During this time, they engaged in skin conductance biofeedback, following the simple instruction to "Relax and allow your skin conductance level to decrease". Biofeedback involved presentation of the participant's skin conductance level in real-time, as well as three biofeedback screens. The first screen presented a jigsaw puzzle, which slowly formed as skin conductance lowered, the second screen presented a flower whose petals opened as skin conductance lowered and the third screen displayed an evening sun which set in tandem with lowering skin conductance.

Skin conductance recording and biofeedback. Skin conductance was recorded using the Mind Media Nexus-10, which is a physiological monitoring and biofeedback device (Mind Media BV, 2004–2006). This device enabled biofeedback of skin conductance during self alert and relaxation training. Skin conductance was recorded

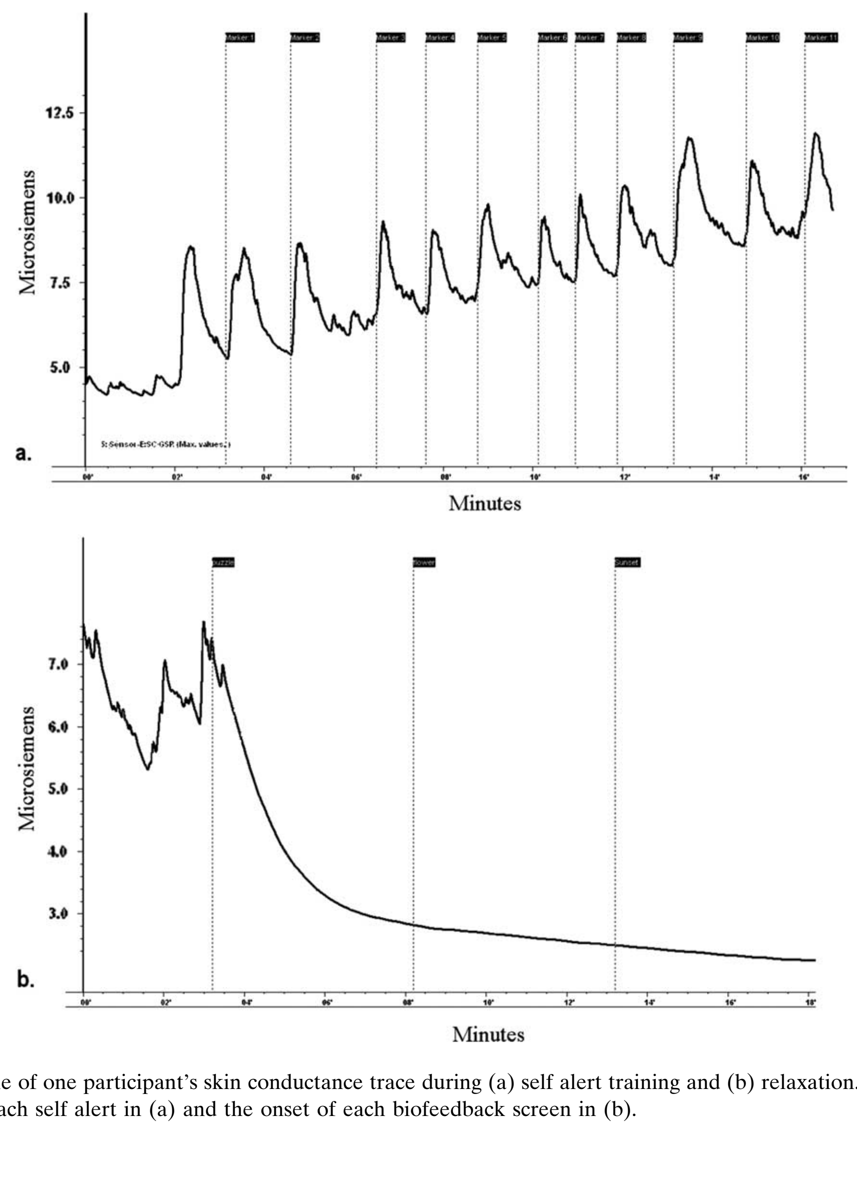

Figure 2. Example of one participant's skin conductance trace during (a) self alert training and (b) relaxation. Markers represent the beginning of each self alert in (a) and the onset of each biofeedback screen in (b).

throughout performance of the CombiTVA paradigm and the resultant trace was analysed using Biotrace software.

Procedure

Participants were assigned to an alert, relaxation, or control group. All participants attended two sessions. During the first session, all participants performed the CombiTVA paradigm. Their skin conductance was measured at the same time. Participants in the alert and relaxation groups then received self alert and relaxation training respectively, whereas participants in the control group did not engage in any training. During the second session, following a second training session, the alert and relaxation groups performed the CombiTVA paradigm again while putting their training into practice (i.e., alerting or relaxing throughout). The control group simply performed the task for a second time. Once again, skin conductance was recorded throughout performance of the CombiTVA paradigm. A series of mixed ANOVAs were conducted in order to determine if there were any significant differences in attentional selectivity and capacity (i.e., t_0, K, C, α) of the three groups across the two sessions. Skin conductance recordings were analysed in order to determine the effects of self alerting during the task.

Results

Visual attentional selectivity and capacity. Mixed ANOVAs with one between-subjects variable, group (three levels: alert, relax, control), and one within-subjects variable, session (two levels: pretraining, posttraining) were performed for each TVA parameter, t_0, K, C, α. Figure 3 presents the means and standard errors for each TVA parameter across each session for each group. Table 1 presents the results of the mixed ANOVAs for each TVA parameter. The lack of an interaction between group and session for any of the TVA parameters suggests that self alerting did not have a significant effect on attentional selectivity or capacity. The only significant findings were a significant effect of session for K, $F(1, 43) = 4.17$, $p = .047$, and C, $F(1, 43) = 22.03$, $p < .001$, indicating that all three groups displayed a practice effect, increasing their K and C values during the second testing session, and a significant effect of group on K, $F(2, 43) = 3.5$, $p = .04$. Figure 3 suggests that the relax group had a higher K value during both sessions. *Post hoc* Bonferroni *t*-tests revealed that the difference between the relax and control group was approaching significance ($p = .056$). The difference between the relax and alert groups was not significant ($p = .14$).

Skin conductance. The mean and variation of the skin conductance trace were analysed to determine if the alert group managed to increase their skin conductance level during the second performance of the CombiTVA paradigm relative to the other groups. Analyses showed that the alert group significantly increased its mean level of skin conductance from 6.17 ($SD = 2.88$) microsiemens during Session 1 to 7.95 ($SD = 3.07$) microsiemens during Session 2, $t(13) = -1.98$,

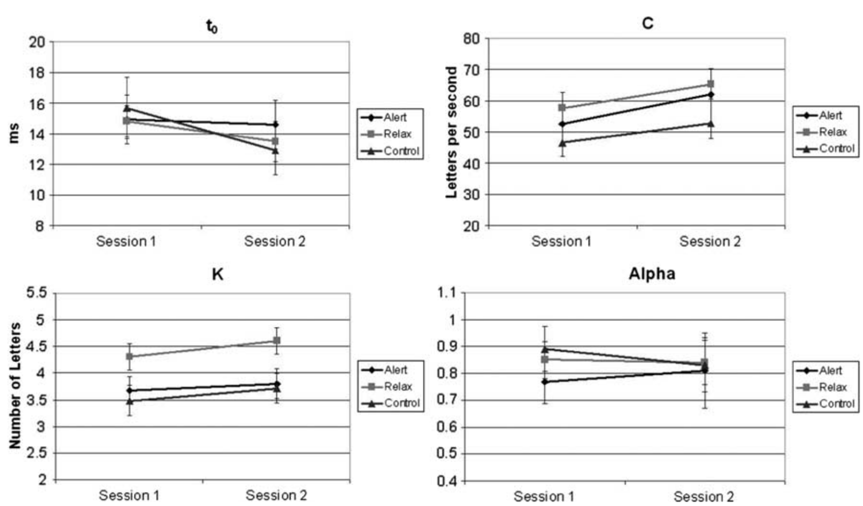

Figure 3. The effects of self alerting on attentional selectivity and capacity. Depiction of the mean value for t_0, K, C, and α for the alert, relax, and control groups during Sessions 1 and 2. Vertical lines represent standard error of the mean.

TABLE 1
The effects of self alerting on attentional selectivity and capacity. Results of the mixed ANOVAs for each TVA parameter

	Group	*Session*	*Group*Session*
t_0	$F(2, 43) < 1$	$F(1, 43) = 2.72$, $p = .11$	$F(2, 43) < 1$
K	$F(2, 43) = 3.5$, $p = .04$	$F(1, 43) = 4.17$, $p = .047$	$F(2, 43) < 1$
C	$F(2, 43) = 1.47$, $p = .24$	$F(1, 43) = 22.03$, $p < .001$	$F(2, 43) < 1$
α	$F(2, 43) < 1$	$F(1, 43) < 1$	$F(2, 43) < 1$

$p = .035$ (one-tailed). The relax group showed a nonsignificant reduction in mean level from 9.74 ($SD = 9.66$) microsiemens to 7.65 ($SD = 4.08$) microsiemens, $t(15) = 1.223$, $p = .24$. The control group showed a significant decrease in mean level from 4.7 ($SD = 2.78$) microsiemens to 3.16 ($SD = 1.76$) microsiemens, $t(12) = 3.27$, $p = .007$. Between subjects comparisons of mean skin conductance level are difficult to make due to the wide variation found in individual baseline levels, which typically vary between 2 and 20 microsiemens (Dawson et al., 2000). In order to compare the changes between the three groups, change scores were created for each participant by expressing the difference between the mean levels for the two sessions as a proportion of the mean level during the first session, i.e., $(S2_{mean} - S1_{mean})/S1_{mean}$. Figure 4 presents the change scores for each group and clearly shows that the alert group had the largest, positive, change score of all groups. A one-way ANOVA revealed a significant difference between the change scores for the three groups, $F(2, 42) = 4.91$, $p = .012$. *Post hoc* Bonferroni *t*-tests showed that the alert group's change score was significantly greater than that of the control group ($p = .01$) but not the relax group ($p = .28$). Note that there was no significant difference between the change scores for the relaxation and control groups ($p = .4$), with the control group actually showing the largest decrease in skin conductance from Session 1 to Session 2.

The coefficient of variation (i.e., standard deviation/mean) was calculated for each session to examine changes in the variation of skin conductance level across sessions while taking account of each participant's mean skin conductance level. Figure 5 displays the coefficient of variation for each group across the two sessions. A mixed ANOVA with one between subjects variable, group (three levels: alert, relax, control) and one within subjects variable, session (two levels: pretraining, posttraining) revealed a significant interaction between group and session, $F(2, 40) = 10.32$, $p < .001$, but no effect of group, $F(2, 40) < 1$, or session, $F(1, 40) < 1$. *Post hoc* paired samples *t*-tests revealed that the alert group showed a significant decrease in coefficient of variation, $t(13) = 4.98$, $p < .001$, the relax group showed a significant increase, $t(15) = -2.19$, $p = .045$, and the control group showed no significant change, $t(12) = -0.202$, $p = .84$, across sessions.

Overall, the skin conductance analyses showed that the alert group increased the mean level and decreased the variation of the skin conductance trace during their posttraining performance on the CombiTVA paradigm. These results suggest

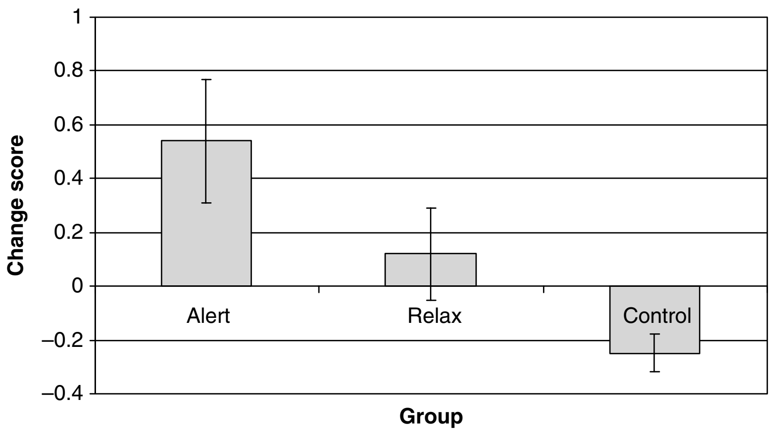

Figure 4. Change in mean skin conductance level for each group from Session 1 to Session 2.

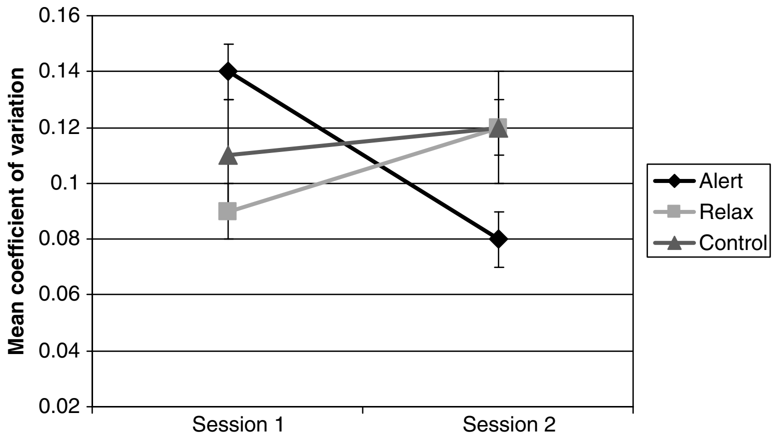

Figure 5. Mean coefficient of variation of skin conductance for each group during Sessions 1 and 2.

that participants in the alert group managed to increase and gain more control over autonomic arousal through self alerting.

Summary of results for Study 1

The results show that apart from significant practice effects for the variables, K and C, and a higher overall K value in the relax group, there were no significant differences between the TVA parameters for the three groups during the two sessions. TVA parameters were not differentially affected by alerting, relaxing or simply performing the CombiTVA paradigm twice. Indeed, despite the alert group managing to enhance autonomic arousal through self alerting while performing the CombiTVA paradigm in the second session, self alerting had no effect on TVA parameters. These results suggest that visual attentional selection and capacity are not enhanced by self alerting, a technique used to maintain attention to task.

STUDY 2: THE RELATIONSHIP BETWEEN SUSTAINED ATTENTION, ATTENTIONAL SELECTIVITY, AND CAPACITY

Method

The relationship between sustained attention and visual attentional selectivity and capacity was examined in two ways. First, correlational and principal components analyses were used to examine the relationship between TVA parameters and performance on the Fixed and Random versions of the SART (Robertson et al., 1997). Second, time-on-task effects during the CombiTVA paradigm were examined to determine whether attentional selectivity and capacity declined with time-on-task.

Participants

Seventy volunteers, including 27 men and 43 women, aged from 20 to 69 ($M = 44.03$, $SD = 14.8$), participated in this study.

Materials

CombiTVA paradigm. See Study 1

Sustained attention tasks. The SART measured fluctuations in sustained attention by measuring the ability to inhibit a response to an infrequent target stimulus in the context of maintaining an ongoing, monotonous action. Numbers between 1 and 9 were presented on screen and participants were required to press a button for every number that appeared but to withhold their response to number 3 (see Figure 6). In the Fixed version of the task, numbers appeared in the fixed sequence, 1–9, and in the Random version, numbers appeared in a pseudorandom order. The numbers appeared in white against a black background and remained for 313 ms. Each digit was followed by a mask, a cross within a circle, which lasted for 1126 ms. Embedded within the mask period was a response cue (63 ms), a thicker cross within a circle. Participants were asked to respond on appearance of the response cue in order to minimise differences in inter- and intraindividual response speeds. There were 225 digits in all, including 25 no-go targets (number 3) and 200 go trials (all other numbers). Each SART lasted

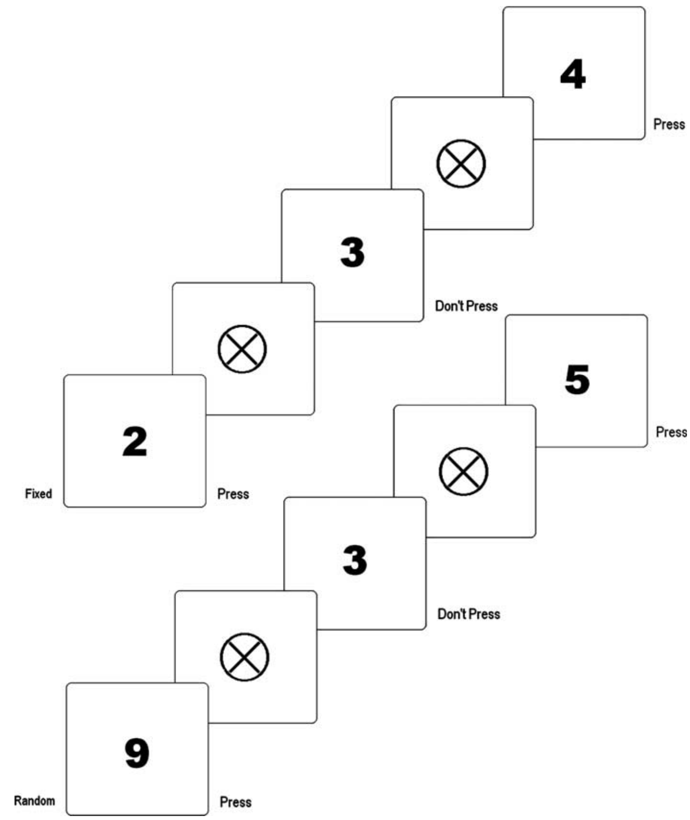

Figure 6. Depiction of the fixed and random SARTs.

approximately 5.4 min. The three measures of sustained attention were errors of commission (i.e., number of times a participant pressed for number 3), errors of omission (i.e., number of times a participant did not press for a go-trial number), and variability of reaction time expressed as the coefficient of variation (i.e., standard deviation/mean reaction time).

Procedure

Participants attended a single testing session during which they performed the CombiTVA paradigm, the $SART_{fixed}$, and the $SART_{random}$, in that order. The first analysis involved conducting principal components analysis on the correlation matrix for the TVA parameters and sustained attention variables. For the second analysis, each participant's data file from the CombiTVA paradigm was divided into thirds and TVA modelling procedures were applied to estimate t_0, K, C, and α for each third (i.e., Blocks 1–3, 4–6, 7–9). Each participant's data file from the Fixed and Random SARTs was divided into two halves and errors of commission, errors of omission, and reaction time variability for each half were compared.

Results

Analysis 1: Principal components analysis. Table 2 presents descriptive statistics for each of the attention variables. Table 3 presents the correlation matrix for the attention variables. It is clear from this table that the correlations between the sustained attention variables and the TVA parameters were small and nonsignificant.

Three principal components analyses were conducted, one including the TVA parameters, t_0, K, C, α, and errors of commission (ERC) on the Fixed and Random SARTs, one including TVA parameters and errors of omission (ERO) on the SARTs and one including the TVA parameters and reaction time variability (RTcov) on the SARTs. The Bartlett Test of Sphericity was statistically significant for all correlation matrices, $\chi^2(15) = 27.37$, $p = .026$; $\chi^2(15) = 46.05$, $p < .001$; $\chi^2(15) = 39.28$, $p = .001$, respectively, suggesting that there was a sufficient number of significant correlations in the matrices to warrant principal components analyses. For each analysis, three components with Eigenvalues greater than 1

TABLE 2
Descriptive statistics for attention variables

Variables	*Mean*	*Standard deviation*	*Minimum score*	*Maximum score*
t_0	15.06 ms	6.5 ms	1 ms	35 ms
K	3.87	1.11	1	6
C	48.75	17.88	20.59	92.87
α	.78	.31	.17	1.6
Random ERC	3.68	4.1	0	20
Random ERO	.76	1.16	0	5
Random RTCov	.2	.05	.11	.33
Fixed ERC	1.09	1.36	0	8
Fixed ERO	2.73	4.37	0	23
Fixed RTCov	.28	.11	.1	.67

ERC = errors of commission; ERO = errors of omission; RTCov = coefficient of variation for reaction time.

were extracted and the matrices were subjected to an orthogonal (Varimax) rotation. These components explained 64%, 70%, and 68% of the variance in the first, second, and third analyses, respectively. In each case, the component solution was examined using a threshold of .4. Tables 4 and 5, and Table 6 present the rotated component matrices for each analysis. The results for each analysis were very similar, with the TVA parameters loading upon separate components to the sustained attention variables, regardless of whether errors of commission, errors of omission, or reaction time variability were included in the analysis. All three analyses yielded three components, one including the sustained attention variables (either ERCs, EROs, or RTcov), one including *K* and *C*, and one including t_0 and α.

Analysis 2: Time-on-task effects. Time-on-task effects during the CombiTVA paradigm were examined by conducting repeated measures ANOVAs with one within subjects variable, time (three levels: Part 1, Part 2, Part 3) and *post hoc* paired samples *t*-tests for each TVA parameter, t_0, *K*, *C*, and α. Table 7 presents the results of the ANOVAs and paired samples *t*-tests and Figure 7 presents the mean values for each variable during each third of the task. The results showed that there was a reduction in t_0 from the first to the second and third parts, an increase in *K* from the first to the second part, an increase in *C* across the task, and no change in α across the task. None of the variables showed a deterioration in performance with time-on-task (see Figure 7).

Time-on-task effects during the Fixed and Random SARTs were examined using paired sample *t*-tests to compare errors of commission, errors of omission, and reaction time variability during the first and second halves of each task. There was no significant change in errors of commission or errors of omission on the Fixed, $t(69) = 0.66$, $p = .51$; $t(69) = -1.51$, $p = .14$, respectively, or Random SARTs, $t(67) = -0.16$, $p = .87$; $t(67) = -0.88$, $p = .38$, respectively. However, reaction time variability, measured by the coefficient of variation for reaction time, increased significantly during the second half of

TABLE 3
Pearson correlations between attention variables

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. t_0	1									
2. *K*	−.183	1								
3. *C*	−.017	.466**	1							
4. α	.065	−.025	.064	1						
5. Random ERCs	.010	.089	−.188	−.107	1					
6. Fixed ERCs	.038	.060	−.089	−.044	.166	1				
7. Random EROs	−.053	−.078	−.072	.014	.367**	.334**	1			
8. Fixed EROs	−.094	−.047	−.160	−.009	.284*	.333**	.561**	1		
9. Random RTcov	.006	−.151	−.078	.014	.472**	−.010	.230	.343**	1	
10. Fixed RTcov	−.068	−.081	−.114	.021	.252*	.167	.357**	.645**	.492**	1

*$p < .05$, **$p < .01$.

TABLE 4
Component matrix for TVA parameters and errors of commission on the fixed and random SARTs

Variables	*Component 1*	*Component 2*	*Component 3*
K	**.854**	.184	−.183
C	**.839**	−.204	.135
Fixed ERCs	.056	**.751**	.146
Random ERCs	−.080	**.729**	−.196
t_0	−.179	.181	**.756**
α	.120	−.201	**.651**

the Fixed ($M = 0.26$, $SD = 0.1$ vs. $M = 0.28$, $SD = 0.13$), $t(69) = -2.38$, $p = .02$, and Random SARTS ($M = 0.19$, $SD = 0.05$ vs. $M = 0.21$, $SD = 0.07$), $t(67) = -2.55$, $p = .013$.

Summary of Study 2 results

Correlational and principal components analyses revealed a lack of relationship between TVA parameters and performance on the sustained attention tasks. The time-on-task analyses revealed an effect of time-on-task for the sustained attention tasks but not the TVA parameters. There was a significant increase in variability of reaction time during the second half of the Fixed and Random SARTs. In contrast, none of the TVA parameters was adversely affected by time-on-task. This finding is particularly remarkable given that the sustained attention tasks lasted 5.4 min while the CombiTVA paradigm took up to 40 min to complete. Together, the findings from Study 2 suggest that attentional selectivity and capacity are independent of the ability to sustain attention and are not vulnerable to decline with time-on-task.

GENERAL DISCUSSION

The TVA provides a quantitative account of attentional selectivity and capacity but does not account for fluctuations in sustained attention.

TABLE 5
Component matrix for TVA parameters and errors of omission on the fixed and random SARTs

Variables	*Component 1*	*Component 2*	*Component 3*
Fixed EROs	**.871**	−.085	−.072
Random EROs	**.871**	−.041	.026
K	−.024	**.840**	−.183
C	−.113	**.828**	.133
α	.119	.172	**.805**
t_0	−.188	−.267	**.623**

TABLE 6
Component matrix for TVA parameters and reaction time variability on the fixed and random SARTs

Variables	*Component 1*	*Component 2*	*Component 3*
Fixed RTcov	**.861**	−.049	−.056
Random RTcov	**.845**	−.094	.046
K	−.091	**.833**	−.191
C	−.068	**.832**	.141
α	.121	.188	**.756**
t_0	−.143	−.256	**.681**

The current set of studies was conducted in order to investigate how the TVA parameters of attentional selectivity and capacity relate to sustained attention. We found, first, that neither efficiency of top-down selection nor attentional capacity was affected by self alerting, a technique involving periodic endogenous alerts which help to maintain attention to task. An alert group, trained to self alert throughout the CombiTVA paradigm, was compared to two control groups, one group trained to relax throughout the task and a passive control group that simply performed the task twice. The results revealed that even though the alert group managed to increase their mean level of skin conductance when alerting throughout the task, all participants displayed a similar pattern of performance across the two sessions regardless of whether they alerted, relaxed, or simply performed the task twice.

In the second study, we found that in a sample of 70 healthy adults, performance on two sustained attention tasks (Robertson et al., 1997) was unrelated to visual attentional selectivity or capacity. Correlational and principal components analyses revealed that none of the components of attentional selectivity or capacity, namely perceptual threshold, VSTM capacity, processing capacity, or efficiency of selection, were related to any of the measures of sustained attention, namely errors of commission, errors of omission, or reaction time variability on the Sustained Attention to Response Task (SART).

Finally, we examined time-on-task effects during the CombiTVA and SART tasks. A well-documented property of sustained attention is its tendency to decline with time. This property has manifested as the vigilance decrement, in the form of reduced target detection and increased reaction times during latter parts of vigilance tasks, which require participants to sustain attention for long periods of time in order to detect infrequently occurring target stimuli (Parasuraman et al., 2000).

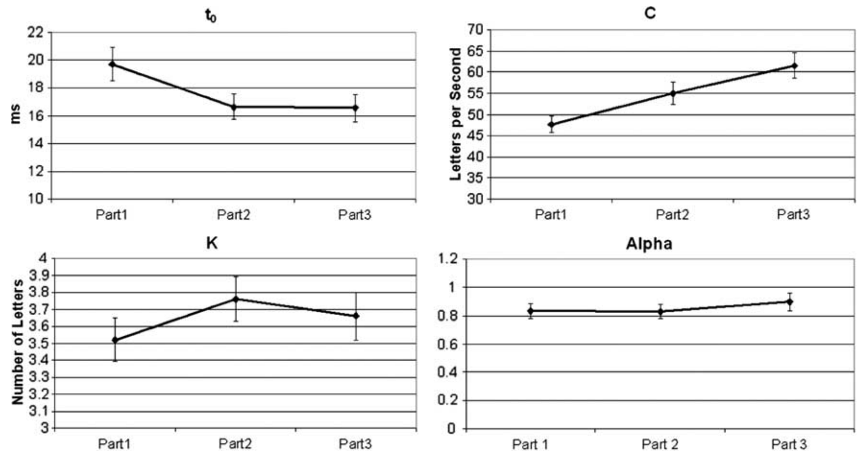

Figure 7. Time-on-task effects. Depiction of the mean value for t_0, K, C, and α during each third of the CombiTVA task. Vertical lines represent standard error of the mean.

In this study, we found time-on-task effects, in the form of increased reaction time variability, during a 5.4 min continuous performance test that is particularly taxing on the sustained attention system. We did not, however, find any adverse effects of time-on-task on the TVA parameters of attentional selectivity and capacity during the 40-min CombiTVA paradigm. Indeed, perceptual threshold, VSTM, and visual processing capacity displayed evidence of improvement throughout the task. Unlike sustained attention, a hallmark of which is its decline with time-on-task, visual attentional selectivity and capacity showed no evidence of adverse time-on-task effects.

Overall, the results suggest that the TVA parameters relating to attentional selectivity and capacity are unrelated to sustained attention. These findings are in keeping with the notion of attention as a multidimensional function, comprised of independent attentional subsystems. This idea is contained in attentional network models, which have proposed the existence of distinct neural networks underlying independent attentional functions (Posner & Fan, 2008; Posner & Petersen 1990), and emanates from factor analytic studies which have repeatedly shown that different measures of attention load upon independent factors (Manly et al., 2001; Mirsky, Bruno, Duncan, Ahearn, & Kellam, 1991; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996; Sturm & Willmes, 1993; Zimmermann, North, & Fimm, 1993).

The results of the self alerting study are in line with a previous study investigating the relationship between intrinsic alertness and TVA parameters. In this study, a lowered state of intrinsic alertness, induced by completing a 50-min vigilance task prior to the selective attention task, had no effect on processing capacity or the efficiency of top-down selection (Matthias et al., 2009). The self alert technique has been previously used successfully by normal healthy adults and adults with ADHD to enhance sustained attention to task during the SART (O'Connell et al., 2008). The results of this previous study and the current study may reflect a dissociation of attentional function in so far as self alerting had a beneficial impact upon sustained attention, but no effect on attentional selectivity or capacity.

The differential time-on-task effects are in keeping with the results of a previous study which examined changes in brain activation with time-on-task during selective and nonselective target identification tasks. Coull, Frackowiak, and Frith (1998) reported deactivation of right frontal and parietal areas with time-on-task during a nonselective but not during a selective task, suggesting that the additional attentional demands of the selective task prevented a decline of sustained attention over time.

Altogether, these findings point to the independence of sustained attention and attentional selectivity and capacity. However, other interpretations are also possible. For example, it is possible that self alerting was not a strong enough manipulation to influence visual attentional selectivity and capacity. Previous studies have shown that aspects of attentional capacity were affected by visual alerting cues (Matthias et al., 2010), manipulations of temporal expectation (Vangkilde et al., 2011) and psychostimulants (Finke et al., 2010). It is possible that in a group of normal healthy adults

TABLE 7
Results of repeated measures ANOVA and *post hoc* paired samples *t*-tests across each third of the CombiTVA paradigm for each TVA parameter

Variable	*ANOVA*	*Significant* post hoc *t-tests*	
t_0	$F(2, 136) = 6.73$, $p = .002$	Part1*Part2	$t(68) = 2.81$, $p = .007$
		Part1*Part3	$t(68) = 3.09$, $p = .003$
K	$F(2, 136) = 3.33$, $p = .039$	Part1*Part2	$t(68) = -2.46$, $p = .017$
C	$F(2, 136) = 25.95$, $p < .001$	Part1*Part2	$t(68) = -4.27$, $p < .001$
		Part1*Part3	$t(68) = -6.22$, $p < .001$
		Part2*Part3	$t(68) = -3.65$, $p = .001$
α	$F(2, 136) < 1$	—	—

who, conceivably, have optimal levels of alertness, a technique to phasically boost endogenous alertness was simply not necessary in order to maintain attention to task. Indeed, Finke et al. (2010) found that psychostimulants increased VSTM and processing capacity only in low-performing participants. For high-performing participants, the boost in arousal from the psychostimulants conferred no additional benefit on their attentional capacity. An interesting idea for a future study would be to investigate the effects of self alerting during the TVA paradigm with a group of people known to experience difficulties with alertness and sustained attention, such as adults with ADHD. A further possibility is that the relaxation therapy was not successful in relaxing participants during Session 2. The results revealed a nonsignificant change in skin conductance from Session 1 to Session 2 for the relax group, whereas the control group, who received no instruction in alerting or relaxation, showed a significant decrease from Session 1 to Session 2. One could argue that the verbal report required during performance of the CombiTVA paradigm prevented a decrease in skin conductance despite the relaxed state of the participants following relaxation therapy. However, the decrease shown by participants in the control group is inexplicable and the possibility that the relaxation therapy was not successful should be borne in mind when evaluating the efficacy of the relax group as an active control group.

It is also possible that the properties of the CombiTVA paradigm influenced the results of this study. Each trial of the CombiTVA paradigm involves a fixation cue, which indicates the commencement of a trial, a brief flash of coloured letters, a mask, and finally, the verbal report of the participant. Each of these events has an alerting aspect and provides exogenous support for the maintenance of attention throughout the task. Sustained attention refers to the endogenous maintenance of attention over time. It is possible that self alerting, a technique designed to enhance sustained attention to task, had no effect on TVA parameters, because it was simply not necessary as participants' attention was maintained by the task itself. This may explain why TVA parameters were not adversely affected by time-on-task. It is possible that TVA parameters did not decline with time-on-task, not because they were impervious to waning sustained attention but because sustained attention did not in fact decline, due to the exogenous support provided by the task itself. One avenue for future research would be to design a selective attention task that does not provide such exogenous support for the maintenance of attention. A task that combined a selective attention element with a need for endogenous maintenance of attention would enable a closer examination of the relationship between these abilities.

The CombiTVA paradigm (Vangkilde et al., in press) is, in fact, a relatively recent version of a TVA-based assessment paradigm. Previous TVA-based studies typically employed separate whole report and partial report tasks in order to estimate parameters relating to attentional capacity and selectivity, respectively. The advantage of the CombiTVA paradigm is that all TVA parameters can be estimated from a single task. However, compared to previous studies (e.g., Matthias et al., 2009), the current paradigm yielded relatively high values relating to top-down attentional selectivity. For example, the mean alpha value for the 70 volunteers, aged 20-69, who participated in Study 2 was .78, $SD = 0.31$ (see Table 2). Although this mean value does not represent an absolute floor effect (which an alpha value of 1.0, indicating nonselectivity on the part of the participant, would represent), it is still quite high. It is unclear at this point whether the high alpha values obtained represent the true attentional selectivity ability of the particular group of participants who took part in this study, who varied widely in age (i.e., up to 69 years old) and background, or are spuriously high due to some property of the CombiTVA paradigm itself. If the latter is true, the utility of the CombiTVA paradigm for estimating top-down attentional selectivity would be compromised. It is likely that future research employing the CombiTVA paradigm with samples of participants with varied characteristics will shed light on this issue.

In summary, using a TVA-based paradigm (Bundesen, 1990; Kyllingsbæk, 2006) as a measure of visual attentional selectivity and capacity in a sample of normal healthy adults, we found that attentional selectivity and capacity were, first, unaffected by a technique designed to boost sustained attention to task, second, unrelated to performance on sustained attention tasks, and third, robust to the adverse effects of time-on-task often seen in vigilance tasks. These results are in keeping with the idea of independent abilities relating to sustained attention, attentional selectivity, and capacity. However, future studies are warranted to further investigate the relationship between these attentional abilities.

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REFERENCES

Bublak, P., Finke, K., Krummenacher, J., Preger, R., Kyllingsbæk, S., Müller, H. J., et al. (2005). Usability of a Theory of Visual Attention (TVA) for parameter-based measurement of attention II: Evidence from two patients with frontal or parietal damage. *Journal of the International Neuropsychological Society*, *11*, 843–854.

Bublak, P., Redel, P., & Finke, K. (2006). Spatial and non-spatial attention deficits in neurodegenerative diseases: Assessment based on Bundesen's Theory of Visual Attention (TVA). *Restorative Neurology and Neuroscience*, *24*, 287–301.

Bublak, P., Redel, P., Sorg, C., Kurz, A., Förstl, H., Müller, H. J., et al.. (2011). Staged decline of visual processing capacity in mild cognitive impairment and Alzheimer's disease. *Neurobiology of Aging*, *32*(7), 1219–1230.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*, 523–547.

Bundesen, C., & Habekost, T. (2008). *Principles of visual attention: Linking mind and brain*. Oxford, UK: Oxford University Press.

Bundesen, C., Habekost, T., & Kyllingsbaek, S. (2005). A neural theory of visual attention: Bridging cognition and neurophysiology. *Psychological Review*, *112*, 291–328.

Coull, J. T., Frackowiak, R. S. J., & Frith, C. D. (1998). Monitoring for target objects: Activation of right frontal and parietal cortices with increasing time on task. *Neuropsychologia*, *12*, 1325–1334.

Dawson, M. E., Schell, A. M., & Filion, D. L. (2000). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary, & G. G. Bernston (Eds.), *Handbook of psychophysiology* (2nd ed), pp. 200–223). New York, NY: Cambridge University Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Reviews Neuroscience*, *18*, 193–222.

Dubois, M., Kyllingsbæk, S., Prado, C., Peiffer, E., Lassus, D., & Valdois, S. (2010). Fractionating the multi-character processing deficit in developmental dyslexia: Evidence from two case studies. *Cortex*, *46*, 717–738.

Duncan, J., Bundesen, C., Olson, A., Humphreys, G., Chavda, S., & Shibuya, H. (1999). Systematic analysis of deficits in visual attention. *Journal of Experimental Psychology: General*, *128*, 450–478.

Duncan, J., Bundesen, C., Olson, A., Humphreys, G., Ward, R., Kyllingsbæk, S., et al. (2003). Dorsal and ventral simultanagnosia. *Cognitive Neuropsychology*, *20*, 675–701.

Finke, K., Bublak, P., Krummenacher, J., Kyllingsbæk, S., Müller, H. J., & Schneider, W. X. (2005). Usability of a Theory of Visual Attention (TVA) for parameter-based measurement of attention I: Evidence from normal subjects. *Journal of the International Neuropsychological Society*, *11*, 832–842.

Finke, K., Dodds, C. M., Bublak, P., Regenthal, R., Baumann, F., Manly, T., & Muller, U. (2010). Effects of modafinil and methylphenidate on visual attention capacity: A TVA-based study. *Psychopharmacology*, *210*, 317–329.

Finke, K., Schneider, W. X., Redel, P., Dose, M., Kerkhoff, G., Müller, H. J., et al. (2007). The capacity of attention and simultaneous perception of objects: A group study of Huntington's disease patients. *Neuropsychologia*, *45*, 3272–3284.

Gerlach, C., Marstrand, L., Habekost, T., & Gade, A. (2005). A case of impaired shape integration: Implications for models of visual object processing. *Visual Cognition*, *12*, 1409–1443.

Habekost, T., & Bundesen, C. (2003). Patient assessment based on a Theory of Visual Attention (TVA): Subtle deficits after a right frontal-subcortical lesion. *Neuropsychologia*, *41*, 1171–1188.

Habekost, T., & Rostrup, E. (2006). Persisting asymmetries of vision after right side lesions. *Neuropsychologia*, *44*, 876–895.

Habekost, T., & Rostrup, E. (2007). Visual attention capacity after right hemisphere lesions. *Neuropsychologia*, *45*, 1474–1488.

Habekost, T., & Starrfelt, R. (2006). Alexia and quadrant-amblyopia: Reading disability after a minor visual field deficit. *Neuropsychologia*, *44*, 2465–2476.

Habekost, T., & Starrfelt, R. (2009). Visual attention capacity: A review of TVA-based patient studies. *Scandinavian Journal of Psychology*, *50*, 23–32.

Ishihara, S. (1960). *Tests for colour-blindness*. London, UK: H. K. Lewis & Co. Ltd.

Johnson, K. A., Kelly, S. P., Bellgrove, M. A., Barry, E., Cox, M., Gill, M., & Robertson, I. H. (2007). Response variability in Attention Deficit Hyperactivity Disorder: Evidence for neuropsychological heterogeneity. *Neuropsychologia*, *45*, 630–638.

Kyllingsbaek, S. (2006). Modeling visual attention. *Behavior Research Methods*, *38*, 123–133.

Manly, T., Anderson, V., Nimmo-Smith, I., Turner, A., Watson, P., & Robertson, I. H. (2001). The differential assessment of children's attention: The Test of Everyday Attention for Children (TEA-Ch), normative sample and ADHD performance. *Journal of Child Psychology and Psychiatry*, *42*(8), 1065–1081.

Manly, T., Owen, A. M., McAvinue, L. P., Datta, A., Lewis, G. H., Scott, S. U., et al. (2003). Enhancing the sensitivity of a sustained attention task to frontal damage: Convergent clinical and functional imaging evidence. *Neurocase*, *9*(4), 340–349.

Matthias, E., Bublak, P., Costa, A., Muller, H. J., Schneider, W. X., & Finke, K. (2009). Attentional and sensory effects of lowered levels of intrinsic alertness. *Neuropsychologia*, *47*, 3255–3264.

Matthias, E., Bublak, P., Muller, H. J., Schneider, W. X., Krummenacher, J., & Finke, K. (2010). The influence of alertness on spatial and nonspatial components of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 38–56.

McAvinue, L. P., O'Keeffe, F., McMackin, D., & Robertson, I. H. (2005). Impaired sustained attention and error awareness in traumatic brain injury: Implications for insight. *Neuropsychological Rehabilitation*, *15*(5), 569–587.

Mind Media BV. (2004–2006). *User manual for the BioTrace + software*. www.mindmedia.info

Mirsky, A. F., Bruno, J. A., Duncan, C. C., Ahearn, M. B., & Kellam, S. G. (1991). Analysis of the elements of attention: A neuropsychological approach. *Neuropsychology Review*, *2*, 109–145.

O'Connell, R. G., Bellgrove, M. A., Dockree, P. M., Lau, A., Fitzgerald, M., & Robertson, I. H. (2008). Self-alert training: Volitional modulation of autonomic arousal improves sustained attention. *Neuropsychologia*, *46*, 1379–90.

Parasuraman, R. (1984). The psychobiology of sustained attention. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 61–101). New York, NY: Wiley.

Parasuraman, R., Warm, J. S., & See, J. E. (2000). Brain systems of vigilance. In R. Parasuraman (Ed.), *The attentive brain* (pp. 221–256). London, UK: MIT Press.

Peers, P. V., Ludwig, C. J., Rorden, C., Cusack, R., Bonfiglioli, C., Bundesen, C., et al. (2005). Attentional functions of parietal and frontal cortex. *Cerebral Cortex*, *15*, 1469–1484.

Posner, M. I., & Fan, J. (2008). Attention as an organ system. In J. R. Pomerantz (Ed.), *Topics in integrative neuroscience: From cells to cognition* (pp. 31–61). New York, NY: Cambridge University Press.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Redel, P., Bublak, P., Sorg, C., Kurz, A., Förstl, H., Müller, H. J., et al.. (2010). Deficits of spatial and task-related attentional selection in mild cognitive impairment and Alzheimer's disease. *Neurobiology of Aging*, 17 June. Advance online publication.

Robertson, I. H., & Garavan, H. (2004). Vigilant attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (pp. 631–640). Cambridge, MA: MIT Press.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). ''Oops!'': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, *35*, 747–758.

Robertson, I. H., Tegner, R., Tham, K., Lo, A., & Nimmo-Smith, I. (1995). Sustained attention training for unilateral neglect: Theoretical and rehabilitation implications. *Journal of Clinical and Experimental Neuropsychology*, *17*(3), 416–430.

Robertson, I. H., Ward, T., Ridgeway, V., & Nimmo-Smith, I. (1996). The structure of normal human attention: The Test of Everyday Attention. *Journal of the International Neuropsychological Society*, *2*, 525–534.

Sheridan, M. D. (1970). New appliances—Sheridan Gardiner Test for visual-acuity. *British Medical Journal*, *1*, 108–109.

Smallwood, J., Fishman, D. J., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin and Review*, *14*, 230–236.

Starrfelt, R., Habekost, T., & Gerlach, C. (2010). Visual processing in pure alexia: A case study. *Cortex*, *46*, 242–255.

Starrfelt, R., Habekost, T., & Leff, A. P. (2009). Too little, too late: Reduced visual span and speed characterize pure alexia. *Cerebral Cortex*, *19*, 2880–2890.

Sturm, W. (1996). Evaluation in therapeutical contexts: Attentional and neglect disorders. *European Review of Applied Psychology*, *46*, 207–215.

Sturm, W., & Willmes, K. (1993). A normative study on the European Attention Test Battery. In F. J. Stachowiak (Ed.), *Developments in the assessment and rehabilitation of brain-damaged patients* (pp. 17–20). Tubingen, Germany: Gunter Narr Verlag.

Vangkilde, S., Bundesen, C., & Coull, J. T. (in press). Prompt but inefficient: Nicotine differentially modulates discrete components of attention. *Psychopharmacology*.

Vangkilde, S., Coull, J. T., & Bundesen, C. (2011). Great expectations: Temporal expectation modulates perceptual processing speed. *Manuscript submitted for publication*.

Warm, J. S. (1984). An introduction to vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 1–14). New York, NY: Wiley.

Zimmermann, P., North, P., & Fimm, B. (1993). Diagnosis of attentional deficits: Theoretical considerations and presentation of a test battery. In F. J. Stachowiak (Ed.), *Developments in the assessment and rehabilitation of brain-damaged patients* (pp. 3–15). Tubingen, Germany: Gunter Narr Verlag.