

Assessing the temporal aspects of attention and its correlates in aging and chronic stroke patients

Nir Shalev, Glyn Humphreys¹, & Nele Demeyere

*Cognitive Neuropsychology Centre
Department of Experimental Psychology, University of Oxford*

Corresponding author:

Nir Shalev

Email: nir.shalev@psy.ox.ac.uk

*Cognitive Neuropsychology Centre
Department of Experimental Psychology
University of Oxford
Oxford OX1 3UD
U.K.*

¹ Following the first submission of this paper, Professor Glyn Humphreys tragically passed away. This paper is dedicated to his memory.

Abstract

Temporal dynamics of attention have been in the spotlight of research since the earliest days of cognitive psychology. Typically, researchers describe two different aspects of the temporal fluctuations of attention: one is in intervals of milliseconds (phasic alertness), and the other over minutes or even hours (tonic alertness or sustained attention). In order to evaluate individual capacities for sustained attention and phasic alertness, most studies rely on variations of the Continuous Performance Task (CPT). Indices of sustained attention and phasic alertness are typically based on reaction times to targets; phasic alertness is related to the change in reaction times following a cue, and sustained attention is related to variability of reaction times during the task. In the following study, we attempted to establish a new approach for studying sustained attention and phasic alertness, not reliant solely on reaction time measures. We developed a new variation of the CPT with conjunctive feature targets and forward and backward masking to induce a higher variability in accuracy. This allowed us to assess an individual's ability to maintain the same level of sensitivity to targets (d' -prime) across a ten minute period on the task as an index for sustained attention. We also assessed reaction times as a function of previous trial type, and suggest previous trial RT benefit might be a marker for an individual's phasic alertness. We demonstrated the use of this task with healthy aging controls and stroke survivors. As a demonstration of external validity of the novel paradigm, we present a correlation between how individual performance drops over time and individual reports of distractibility in everyday life on the Cognitive Failures Questionnaire. In addition, we found significant differences between the patient and control groups in our proposed marker of phasic alertness. We discuss the implications of our study for

current assessment tools, as well as general differences in phasic alertness between clinical and neurologically unimpaired groups.

Introduction

Sustained attention: constructs and measures

Attention is among the most studied cognitive functions of the human mind: In a constantly changing environment, the ability to maintain attention over time is crucial for any adaptive behaviour. Although referred to as a single construct, contemporary theories in cognitive neuroscience characterize attention as a complex, multifaceted system (Parasuraman, 2000; Petersen & Posner, 2012; Posner & Petersen, 1990; Humphreys & Riddoch, 1993). Attention also has its own dynamic fluctuations over time (Coull, 2004). Some temporal aspects of attention are quite intuitive: for instance, there are times during the day (or the night) when we have less capacity to pay attention to any given task. Nevertheless, beyond the common-sense meaning of attentional changes over time, many studies have been dedicated to quantifying and understanding, in a more precise way, the temporal dynamics of attention in various time frames – ranging from milliseconds to days. Variations in attention over time are often discussed in relation to concepts such as Sustained attention, Arousal, Vigilance and Alertness (e.g. Oken, Salinsky, & Elsas, 2006). Arguably though, these constructs are not well defined. Oken, Salinsky & Elsas (2006), for example, point out that the term *vigilance* has been used interchangeably to describe maintaining attention over time, the level of responsiveness to danger, and a general level of arousal in a sleep-wake scale.

One way to reconcile the different definitions of the temporal dynamics of attention is by defining different time scales of interest. Indeed, researchers often describe two levels of vigilance/alertness: “phasic alertness”, often defined as the alertness of the system in a short period following a cue (e.g., Sturm et al., 1999;

Coull et al., 2001), and “tonic alertness” (e.g., Raz & Buhle, 2006; Petersen & Posner, 2012), often studied by measuring how attentional performance decays over a longer time period (e.g. 1 hour) (e.g., Mackworth, 1964). Phasic alertness may be thought equivalent to momentary vigilance and tonic alertness to sustained attention. Throughout this article, we will use the term “sustained attention” instead of “tonic alertness”, since it is currently used more regularly in the literature. Logically, sustained attention and phasic alertness must be distinct: if an individual has a lower alertness level at any given moment (e.g., responding more slowly to a basketball pass), this does not imply that his/her performance will also deteriorate more over time.

Conversely, one can imagine a highly responsive, sharp individual, whose performance fluctuates over time more than his/her peers with a lower alertness. These delineations also appear to have some correlates in cognitive and physiological research (e.g., Nebes & Brady, 1993; Sturm & Wilmes, 2001; Posner, 2008; Yanaka et al., 2010; for a review see also Oken, Salinsky & Elsas, 2006). For example, Sturm and Wilmes (2001) identified a right hemispheric frontal, parietal, thalamic and brain-stem network with sustained attention. When testing phasic alertness, they identified further activity in the left hemisphere, mostly in frontal and parietal structures.

Assessing Sustained Attention in clinical populations

Sustaining attention over time is a prerequisite for responding to the constantly changing environment. Difficulties in sustaining attention have been demonstrated to correlate for example with learning, and behavioural and emotional difficulties in adolescence (e.g., Shalev et al., 2015), with difficulties in professional development (e.g., Kalechstein, Newton, & van Gorp, 2003), and in driving (e.g., Schmidt et al.,

2009). Impairments in sustained attention are also apparent in brain injury cases (e.g., Robertson et al., 1997a; Hyndman & Ashburn, 2003). In addition, poor sustained attention has been associated with other attentional disorders (e.g. spatial inattention, Robertson, 2001), poor recovery from motor problems (Robertson et al., 1997b) and unilateral neglect (Robertson, 1995).

The most common assessment for sustained attention is arguably by measuring performance on variations of the Continuous Performance Test (CPT) (e.g., Chen & Faraone, 2000; Conners & Staff, 2000). In a typical CPT, a stream of stimuli appears at the centre of focus every few seconds, and the participant is required to respond only to an infrequent target. Performance is assessed in terms of accuracy, but there is often a (near) ceiling effect here (Halperin et al., 1991; Robertson et al., 1997a). Therefore, experimenters have also adopted other measures such as the standard deviation of reaction times (RT-STD) during the task as a proxy of the variability of sustained attention (e.g., Shalev et al., 2011). Another approach has been to increase the task difficulty in order to induce a higher level of errors, and allow the assessment of performance based accuracy.

Additional manipulations to increase the sensitivity of accuracy-based outcome measures have been carried out through increasing the memory load (e.g., Chen & Faraone, 2000), the perceptual load (e.g., Parasuraman, Mutter, & Molloy, 1991) and the demands on response inhibition (Robertson et al., 1997a). Here however there may be other difficulties introduced, especially in the application of measures of sustained attention to particular populations of participants. For example, (i) relying only on the speed of response can be problematic with older participants, who are reported to adopt different speed-accuracy criteria compared with younger adults (e.g., Birren & Fisher, 1995); and (ii) increasing load may confound the pure

measure of sustained attention by introducing demands on memory, inhibitory control etc.

Measuring tonic and phasic alertness

Only rarely do researchers account for the two aspects of alertness (tonic and phasic) within the same task, and often the two terms are used interchangeably (though see Roca et al., 2011). For example, while phasic alertness may be defined by comparing response times for pre-cued vs. non-cued targets (e.g., Callejas, Lupiáñez, & Tudela, 2004), phasic alertness may also be modulated by factors such as the trial history even in an uncued condition. It would be incorrect to assume that uncued conditions selectively tap sustained attention. Conversely, when assessing sustained attention based on a target sensitivity measure (d') (e.g., Corkum, Byrne, & Ellsworth, 1995), it is very likely that the momentary level of alertness (i.e., phasic alertness) contributes to the detection of a target; We explicitly argue that theoretically, an individual with a lower level of phasic alertness may have a higher probability to miss a target, or in other cases to confuse targets and distractors.

In the current study, we aimed to assess sustained attention while also trying to estimate phasic alertness under similar conditions. In order to do so, we propose a new paradigm where we hope to increase the error rate, inducing higher variability in accuracy-based outcome measures. Combined with individual RTs, we intend to extract multiple indices for both aspects of attention. We will do so based on the following theoretical line: sustained attention will be assessed based on changes in performance **over time**; a potential correlate of phasic alertness will be assessed based on RTs to targets as a function of the previous stimulus (distractor vs. target).

By assessing sustained attention based on accuracy, we attempt to provide a patient-friendly assessment tool. This is particularly important given the clear functional outcomes of limited sustained attention: one could easily imagine how important it is for elderly individuals after a stroke to sustain attention while organizing their medicine or boiling water. However such populations generally have slower responses (e.g., Birren & Fisher, 1995), thus using solely RT-based outcome measures can be problematic.

Assessing phasic alertness is a different case. As opposed to the case of sustained attention, which can be measured by accuracy alone, phasic alertness is *defined as the reaction time to a target following a cue* (e.g., Sturm et al., 1999; Coull et al., 2001). In our study, we will evaluate the change in RTs to targets following a target-trial compared to a distractor trial. In other words, we will try to consider a target appearing in the previous trial as a pre-cue. If indeed a change in RT as a function of the previous trial is observed, this potentially could be attributed to phasic alertness. Although the “optimal” Inter-Stimulus Interval (ISI), for a pre-cue serving as a warning signal, is relatively short (approximately 500ms, see Posner & Boies, 1971), under some conditions there could be a lasting effect of a pre-cue following a warning interval of 5 seconds (Posner & Wilkinson, 1969 in Posner & Boies, 1971). Such a long lasting warning interval effect was also found in many studies of simple reaction times following a varying foreperiod (for a review see Niemi & Näätänen, 1981). In the current study we compared clinical and non-clinical populations: the temporal interval of a pre-cue may be prolonged in the case of a clinical population; for instance, Husain and his colleagues (1997) demonstrated longer intervals for orienting temporal attention in patients with neglect by showing evidence for an Attentional Blink after intervals of approximately one and a half seconds.

Evidence suggests that phasic alertness is associated with multiple cognitive faculties, such as task switching (e.g., Meiran, Chorev, & Sapir, 2000) and executive control (e.g., Weinbach & Henik, 2011), and also affiliated with cognitive impairments such as hemispatial neglect (e.g., Robertson et al., 1998). This involvement of phasic alertness in so many mechanisms is also supported by physiological data, according to which the brain activation of phasic alertness is widespread over the two brain hemispheres (Sturm & Willmes, 2001). Nevertheless, although it is involved in many cognitive functions, impaired phasic alertness will not necessarily manifest itself clearly in daily activities. The main reason for this is the time-frame: phasic alertness operates in milliseconds, as opposed to sustained attention which can be defined in seconds, minutes and even hours. We stress this point because compared to sustained attention, verifying the ecological validity of phasic alertness is not as transparent: whereas sustained attention can easily be attributed to everyday distractibility, a few milliseconds difference in selecting a target is harder to describe at the symptomatic-behavioural level. There is nonetheless an interesting prediction in the case of the current research: given the wide-spread networks underlying phasic alertness, there is potentially a higher probability for phasic alertness to be influenced by any damage to the brain after stroke (non-specific / non-localised). Therefore, although it might be less transparent behaviourally, we might expect to observe differences between patients and controls in our proposed marker of phasic alertness. Such group differences may not be observed in sustained attention given its relatively focal loci in right frontal and parietal regions (e.g. Molenberghs et al., 2009).

Subjective reports of sustained attention and objective measures

In order to attribute ecological validity to the measures of sustained attention, people with sustained attention difficulties would be expected to experience attentional lapses in real life situations. Ishigami & Klein (2008) reviewed the existing literature on how attentional capacities are related to self-reports of cognitive difficulties (as defined by the Cognitive Failures Questionnaire, CFQ, (Broadbent et al., 1982)). They included fourteen studies but only three directly assessed sustained attention, and arguably, even these tests involved executive cognitive functions (Ishigami & Klein 2008). At least one study, by Robertson and colleagues (1997a), demonstrated a correlation ($r = -.27$) between performance on a paradigm (the SART²) putatively assessing sustained attention and self-reports of cognitive failures in a group of 60 participants. However, as Ishigami and Klein (2008) note, participants were required to respond to all distractors and withhold their response when they identify a target and so the test has strong components of response suppression (Robertson et al., 1997a).

Wallace, Kass, & Stanny (2002) studied the CFQ and identified four different cognitive constructs: Distractibility, Memory, Blunders and Naming. In previous studies of the relation between self-reports on the Cognitive Failure Questionnaire and performance in a sustained attention task (e.g., Ishigami & Klein, 2008), no correlation was established between performance and any specific questionnaire factor. Instead, correlations were established only with the general questionnaire score. This is quite surprising: between the four proposed questionnaire factors, only one seems to be directly related to sustained attention – the Distractibility factor. It is hard to imagine how the Naming factor, for instance, can be related to measures of

² The Sustained Attention to Response Task—SART was developed in order to assess sustained attention. The task involves withholding of key presses to an infrequent target in a continuous performance task (see Robertson et al., 1997a)

sustained attention. We hypothesised accordingly that there would be a specific correlation between sustained attention and the Distractibility factor, which seems likely to be the best candidate to represent sustained attention. Conversely, a factor like Naming that is purely linguistic probably should not correlate highly with any measure of attention.

Current study

The current study had three main goals: first, to try to assess sustained attention using a novel paradigm. Second, we attempt to identify potential indices for measuring phasic alertness. Finally, we wished to demonstrate a relationship between performance on sustained attention indices in our new task, and performance lapses in everyday life as reflected in the Distractibility factor of the CFQ. We will attempt to measure this construct in a clinical group of chronic stroke survivors and in a neurologically healthy control group.

We hypothesized that the strongest correlation between task performance and the Distractibility factor will be found when using an index based on change over time, namely the d-prime cost (differences in target detectability between first and second halves of the task). We also hypothesized that the overall d-prime parameter, which may be confounded by phasic alertness and perceptual parameters, will not provide a strong measure for sustained attention. The RT-StD parameter, normally the golden-standard in measuring sustained attention, may also fail to provide a strong correlation with subjective reports, because this variable can be confounded by motor difficulties and general slowness in patients and older participants. With respect to indices of phasic alertness, we hypothesized that we will observe a cueing effect based on the nature of the previous trial. When taking into considerations previous

experiments showing longer intervals for a warning signal in some clinical populations, we predict that this cueing effect will be specific to the clinical group.

Experimental investigation

In order to assess sustained attention and phasic alertness, we used a Masked Conjunctive Continuous Performance Task (MCCPT). The task is based on a standard continuous performance task (CPT), where subjects are requested to identify a target during the continuous serial presentation of distractor and target stimuli. Following the work of Shalev et al., 2011, a key feature of the task is the use of conjunctive distractors that may have the same colour or shape as a conjunction target. Conjunctive distractors should increase the demands on selection (relative to when distractors share no features with targets) since they match one target attribute of the target (Shalev et al., 2011), while not confounding performance with a memory- or response-inhibition load. Finally, we introduced a mask between each target and distractor stimulus. Under masking conditions participants may need to recruit additional attentional resources in order to enhance visual perception (e.g., Muller & Humphreys, 1991), to overcome the perceptual degradation caused by the mask. Furthermore, the mask also served as a static placeholder for visual stimuli, and in this way it should decrease effects of the abrupt onset of targets. The sudden appearance of visual stimuli at the attended location characterizes most variations of CPT tasks, and may contaminate performance by the bottom up cueing of attention (e.g., Theeuwes, 1991).

Due to the introduction of perceptual degradation and the lack of abrupt stimulus onsets, the MCCPT should provide a sensitive marker of alertness. By relying on perceptual parameters derived from the Signal Detection Theory (SDT;

Green & Swets, 1966), we induce a higher interpersonal variability compared to standard CPTs where accuracy performance often reaches ceiling (e.g., Halperin et al., 1991; Robertson et al., 1997a). The SDT parameters also mean that the outcome indices are not related to RTs – an important feature in measuring performance with clinical populations, which often suffer from motor problems (e.g. Ada et al., 1996; McCrea & Eng, 2005) and a general decrease in speed (Birren & Fisher, 1995).a

The MCCPT task was administered to a group of older neurologically healthy adults and a group of chronic stroke survivors. They were all also asked to complete the CFQ. We assessed whether the MCCPT task was sensitive to lapses in sustained attention and phasic alertness and whether these lapses related to problems present in everyday life detected through the CFQ.

Methods

Participants

23 chronic stroke survivors and 37 neurologically healthy adults participated in this study (total N=60).

Stroke survivors (*clinical group*): All stroke survivors were at least one year post stroke at the time of testing. Their average age was 62.73 years (SD=12.12), and they were all part of a regular pool of volunteers at the Oxford Cognitive Neuropsychology Centre. Patients were not selected based on their lesion or cognitive deficit. Instead, we aimed to include everyone with the capacity to complete the task.

An overview of the patients is given in Table 1, and Figure 1 provides a lesion overlay of the patients for who scans were available.

[TABLE 1 about here]

[Figure 1 about here]

As appears in Table 1, there were only nine patients with right hemisphere damage, and only three of which had lesions in either parietal or frontal cortices (with only a small overlap between the lesions in those regions). This is particularly important in light of the established relation between right frontal-parietal damage and impaired sustained attention (e.g., Sturm and Wilmes, 2001): based on this sample, we might not expect to find any group differences in sustained attention between the clinical and the non-clinical group.

Adult control group (*control group*): Thirty-seven naive volunteers participated in this experiment (22 women, 5 left-handed). They were all regular volunteers at the Oxford Cognitive Neuropsychology Centre. All had normal/corrected-to-normal eyesight (mean age 68.21, SD= 7.72). They were compensated for their time (payment of £10 per hour, inclusive of travel expenses).

Apparatus

A PC with Intel i7 processor and a dedicated 2GB AMD video card was used for displaying stimuli and recording data. The task was generated using NBS presentation software (Neurobehavioral systems, Albany, CA). The stimuli were presented on a ViewSonic V3D245 LED monitor, with screen resolution of 1080X1920 and a screen refresh rate set at 100Hz allowing display times varied in gaps of 10ms. All stimuli were preloaded to memory using the presentation software, to guarantee minimal temporal noise.

Stimuli

A coloured mask (*Mask*), comprised of four superimposed figures in different colours (square, triangle, circle and hexagon) appeared at the centre of the screen. The total size of the mask occupied 3x3 degrees visual angle. In order to avoid habituation effects, we generated minor movements to the Mask. The movement was generated by alternating every 10-20 milliseconds between two mask-images, one of which had thicker outlines for the superimposed figures (the two alternating mask images are illustrated in Figure 2a). The mask appeared at the centre of the screen and disappeared only when it was replaced by either a target or a distractor shape for 150ms; the mask then reappeared immediately, generating pre- and post-masking of each target or distractor. The target shape was a red circle, and the distractor stimuli were either similar in colour to the target (red hexagon and red triangle), similar in shape (blue circle and red circle), or completely different (yellow and blue hexagon). All distractor types appeared in an equal distribution. All distractors and target shapes circumscribed a square of 3° X 3° visual angle. The interstimulus interval was jittered between 1000 and 5000ms (See Figure 2b for a schematic outline of the experimental procedure). Participants were told that the static shape which appeared at the centre of the screen (the mask) would be replaced every few seconds with another shape which would appear briefly. The task was to press as fast as possible whenever participants recognized a *red circle* at the centre of the screen. Participants were further instructed to do nothing when they saw any other shape.

[Figure 2 about here]

Procedure

The task started with a short practice block (15 trials), and the experimenter monitored subjects' response at this stage to ensure the instructions were clear. After finishing the practice session, the participants performed the whole session without any break until the task terminated after approximately 10 minutes. The task was comprised of 180 trials. The target appeared on 60 trials (33% *target*); and there were 120 *distractor* trials (66%) in which one of six possible distractors appeared on the screen in a randomized order [red square / red triangle / blue circle / blue triangle / yellow circle / yellow triangle]. In addition to performing the computerized task, all participants filled in the Cognitive Failure Questionnaire (CFQ) (Broadbent et al., 1982).

Questionnaire

The Cognitive Failure Questionnaire consists of twenty-five questions over two pages. The question scores contribute to four separate factors labelled Memory, Distractibility, Blunders and Names (Wallace, Kass, & Stanny, 2002). For each question, participants were requested to rank, on a scale from zero to five, how often different occasions of cognitive failures had occurred to them over the last six months (Broadbent et al., 1982).

Statistical analysis

For each participant, we extracted data about the correct reports of targets, the number of omission (“miss”) errors and the number of commission (“false alarm”) errors, as well as reaction times (RT). These measures allowed us to assess individual

performance in different conditions, according to multiple indices: a) the standard deviation of reaction time; b) perceptual sensitivity for discriminating the target from the distractors (d'), in accordance with the signal detection theory (SDT); c) sensitivity cost (defined as the subtraction of d' during the second half of the task from d' during the first half); d) previous trial benefit (defined as the difference between RTs for a target when previous trial was distractor and when previous trial was a target).

Results

Questionnaire data

Fifty-eight out of sixty participants completed the questionnaire in full (two participants, one patient and one control, missed items and were removed from this analysis). Questionnaire scores were calculated for each group (patients and controls) on four factors: Distractibility, Memory, Blunders and Names, as well as a general task score (similar to Wallace, Kass, & Stanny, 2002). The group averages of reported symptoms are illustrated in Figure 3; the inter-correlations of the questionnaire factors for the full group (N=58) appear in Table 2

[Figure 3 about here]

[Table 2 about here]

A pairwise comparison between the groups on each factor revealed there were no significant differences in any of the dimensions. The only factor which can be considered as marginally significant was the “blunders” dimension, with a slightly higher frequency of blunder events (e.g., bumping into people, dropping things) for patients (average score 10.19) compared to controls (average score 7.67)

($t(56)=1.762$; $p=.084$ (uncorrected); 95%CI[-0.27, 4.33]). All other p values for comparing the groups were higher than 0.1.

The results from the questionnaire present a major implication for our research: on a group level, in most factors, the patient sample did not differ in subjective experiences of everyday cognitive failures (compared to the neurologically healthy sample). Therefore, we might expect that a similar pattern will be found when comparing the outcome measures of the cognitive task (MCCPT).

MCCPT: Descriptive statistics

Descriptive statistics for various performance parameters on each group (patients and controls) are summarized in Table 3.

[Table 3 about here]

We removed two participants from the patient group (P#21, P#22) who were performing at chance level. P#21 had damage to his fusiform gyrus, which is often associated with difficulties in processing visual features (e.g., Tyler et al., 2013). P#22 had also damage to her cerebellum, which may have caused difficulties in performing a perceptual discrimination task with speeded responses (e.g., Gao et al., 1996).

MCCPT: Inter-correlations of task parameters

Our main parameters for assessing sustained attention were d' , d' -cost (change in d' between two halves) and RT-STD. A correlation matrix of the three parameters appears in Table 4.

[Table 4 about here]

Two parameters were correlated significantly with each other: d' and RT-STD ($r = -.339$; $p = .009$). Interestingly, the only parameter that did not correlate with the others was the d' -cost. These results support the proposed distinction according to which RT-STD and overall d' are not (pure) measures of maintaining alertness during the task. Sustained attention, is then reflected through the d' -cost parameter.

MCCPT: Performance decrement

In order to ensure our task did require sustained attention, we searched for indications of a decrement in performance over time. While in a typical continuous task, automated attentional processes may cause improvement in performance over time (e.g., Fisk & Scerbo, 1987), a task that requires sustained attention should keep such practice effect at a minimum. In an extensive review paper of sustained attention, Sarter, Givens, & Bruno (2001) suggest that although practice effect often leads to ceiling effects in target detection (i.e., d'), a decrement in performance should be observed in increasing reaction times during the task. In the same line, we calculated the average RTs and RT-STDs for correct responses on every third of the task³, in order to assess whether there is a linear decline in performance over time. A repeated measures ANOVA for RT over three thirds ('blocks') revealed a significant main effect of 'block' ($F(2,118) = 5.464$; $p = .005$; partial $\eta^2 = .085$), with a significant linear contrast ($F(1,59) = 9.209$; $p = .004$; partial $\eta^2 = .135$) with increasingly higher RTs over time. The change in RT over time is depicted in Figure 4a. A similar pattern was found for the RT-STD, with a significant main effect ($F(2,118) = 8.361$; $p < .001$; partial $\eta^2 = .124$). Once again, this effect was fitted to a linear contrast ($F(1,59) = 12.157$; $p = .001$; partial $\eta^2 = .171$). Change in RT-STD over time is in Figure 4b.

³ Splitting the task into three parts is the minimum split required for the evaluation of a linear contrast. With the current number of trials, even when dividing to only three groups, we were left with a relatively small number of valid trials (approximately 20). Therefore, we considered thirds as the maximum number of units we could reliably estimate.

[Figure 4 about here]

MCCPT: Comparing group performance

Although there was no significant difference in most factors of the questionnaire, we still might expect to find differences between patients and controls based on performance in the MCCPT. We compared the two groups on the main 3 measures: RT-STD, d' , and “ d' cost”.

These group comparisons revealed a significant difference in two of the task parameters. Descriptive statistics are presented in Table 5. The patient group had a greater variability in their reaction time compared to the control group ($t(56)=2.198$; $p=.032$; 95%CI[2.53,54.51]). When comparing target detectability parameter (d'), patients had an overall lower target detectability compared with controls ($t(56)=2.66$; $p=.013$; 95%CI[0.11,0.87])⁴.

[Table 5 about here]

MCCPT: Previous Trial Benefit

As part of our attempt to assess phasic alertness, we calculated the reaction times for targets as a function of previous trial (N-1). We calculated the average of RTs for targets with a target on N-1, and for targets with a distractor on N-1. The main rationale behind this approach was the search for a “cueing effect” in a task without cues. Instead, we considered a target-trial as an alerting event, which may influence a consecutive trial.

We carried out a 2 (Group) X 2 (Target/non-target on N-1) mixed design ANOVA, which revealed a significant main effect for the N-1 factor (target vs. no-

⁴ this comparison was based on an adapted version of t-test for comparing groups without equal variance, after Levene's Test for Quality of Variance (Levene, 1960) revealed a significant difference between groups; $F=7.121$; $p=.01$

target) ($F(1,56)=5.916$; $p=.018$; partial $\eta^2=.096$) and a significant interaction ($F(1,56)=7.115$; $p=.01$; partial $\eta^2=.113$). There were no overall group differences in RTs. The results are illustrated in Figure 5. Following the ANOVA, we analysed the interaction by performing a set of paired comparisons. We learned that the source of the interaction is a faster RT in the patient group in cases where previous (N-1) trial was a target (533ms) comparing to non-targets (559ms) ($t(20)=2.613$; $p=.017$; 95%CI[5.07;45.91]). There were no significant differences between RTs for N-1-target and non-target within the control group.

[Figure 5 about here]

The observed effect is in line with our hypothesis that there are group differences in levels of phasic alertness. Whenever a target appeared following another target, reaction times of patients were comparable to the control group. While the patient group benefited from a previous trial with a target, there were no effects of prior trial type on the control group. Potentially, the reason for the lack of a cueing benefit in the control group was the length of the warning interval: the minimum ITI was 1100ms. Based on previous studies with neurologically unimpaired participants, the optimal warning interval is approximately 500ms (Posner & Boies, 1971). However, with a clinical group, this interval might be extended. For example, the temporal dynamics of attention in neglect patients has been found to be different from controls, with longer intervals of temporal orienting (Husain et al., 1997).

Task performance and questionnaire data

We estimated the correlation between three task-parameters: d' , d' -cost and RT-STD; and four questionnaire factors: Distractibility, Memory, Blunders and Naming (Wallace, Kass, & Stanny, 2002). We grouped all participants together for

the correlation analysis as it aims to describe individual relations, irrespective of group membership.

[Table 6 about here]

Our correlation matrix (Table 6) shows that the Distractibility factor was correlated with d'-cost. We calculated the correlation between Memory and d'-cost while controlling for the Distractibility factor. The reason for doing so is that the two factors were constructed of some overlapping questionnaire items (Wallace, Kass, & Stanny 2002). Therefore, by calculating the partial-correlation without the Distractibility factor, we could learn whether there are any exclusive memory-related items that correlated with the d-prime cost. When we repeated the correlation analysis while controlling for distractibility in a partial correlation test, the correlation between memory and d-prime cost disappeared ($r=.12$; $p=.38$). Conversely, when repeating a similar procedure while controlling for memory, the correlation of Distractibility and d'-cost remained high ($r=.53$; $p<.001$). A scatter plot of the correlation between d'-cost and the Distractibility factor is presented in Figure 6.

[Figure 6 about here]

Interestingly, the results show how a large proportion (58%) of the participants had a negative d'-cost value – meaning they actually improved between the two halves. This could be a result of improvement in performance due to a perceptual learning (e.g., Ahissar & Hochstein, 1997) or a more general learning (e.g., Shuell, 1986). Indeed, such improvement in target detection due to practice effect may occur in sustained attention tasks (see Sarter, Givens, & Bruno, 2001). As demonstrated in a previous section, a general performance decrement was evident in longer RTs and RT-STDs over time. Nevertheless, we explicitly argue that assessing sustained

attention by evaluating RTs in a clinical or ageing population is not a pure measure for sustained attention: it can be influenced by either fluctuation in phasic alertness, motor difficulties or general slowness. Indeed, when we estimated the slopes for the change in RT and RT-STD over three blocks (thirds) of the session, and correlated these slopes with the self-reports of distractibility on the CFQ, no correlation was found (all p values $>.2$). Since we observed a main effect for the group factor when comparing mean RT-STD, we repeated the same procedure separately for each group. Once again, no significant correlations were observed (all p values $>.1$). These null effects are in line with our suggestion that RT based measures can be problematic when used with unique populations. We suggest that the strong correlation of d' cost and distractibility, together with the lack of correlation between distractibility and any RT based indices, provides an “ecological” validation to our claim that d' cost can be regarded as a sustained attention measure.

Discussion

In this study we successfully demonstrated how the MCCPT paradigm can assess sustained attention without relying on reaction times, and that a particular measure, the d' -cost, was directly related to measures of self-reported symptoms. The paradigm proved itself to be sensitive enough to assess attention with an older adult control-group, and at the same time simple enough to be carried out by chronic stroke survivors.

Our results highlight a few important conclusions. First, this is the first study (that we are aware of) that demonstrates a specific correlation between the Distractibility construct in the CFQ and sustained attention. In addition, we managed to find this correlation with a very straightforward outcome measure: the way

participants managed to maintain their level of performance during the sustained attention task (MCCPT) was correlated with their subjective reports of lapses in attention in daily activities (CFQ), and specifically with how distracted individuals are during the day. Previous studies have managed to relate performance on sustained attention tasks and the general score of the CFQ, which includes four factors: Distractibility, Blunders, Naming and Memory (e.g., Robertson et al., 1997a). The correlations reported are not only non-specific, but also smaller than observed here.

There are two possible reasons why we managed to find a stronger correlation compared with Robertson and colleagues (1997a): first, we operationalized sustained attention as the change over time in performance, instead of extracting a general accuracy measure; and we maintained sustained attention as the main construct we are testing, without involving high requirements for response inhibition or memory. Second, we suggested that d-prime and RT-StD are not the best indices for sustained attention. d-prime, as reflecting the general sensitivity to targets along the task, may reflect more than a single construct: it can be influenced by both phasic alertness and sustained attention. RT-StD can be a problematic way of assessing performance with clinical populations and elderly participants, who may suffer from non-specific slower responses and motor problems. In line with this argument, there were no significant correlations between any of the CFQ factors and these indices. Such overall, non-specific group differences in accuracy and RTs were recently also observed in a study by Rinne and colleagues (2013) where a group of stroke patients was assessed using the Attentional Network Task (ANT: Fan et al., 2002). Importantly, they did not find any group differences with regards to the specific attentional indices (i.e. cue and flanker).

Evidently, there were no group differences in our measure of sustained attention. The lack of any group difference in d-prime cost is also supported by the symptomatic-behavioural data we acquired: both patients and controls reported similar levels of cognitive failures, and in particular, both had the same levels of reported Distractibility. These findings are not that surprising given our sample group: we included a group of stroke patients from the chronic stroke panel at the Cognitive Neuropsychology Centre. They were not selected based on a particular lesion site or behavioural profile, with a majority of left hemisphere damage. Within the group of the right hemisphere patients, only three had frontal or parietal damage. In addition, one might argue that using questionnaire data based on self-reports of stroke patients may prove to be unreliable due to potential anosognosia after stroke (e.g., Orfei et al., 2007). To our knowledge, none of our patients was anosognosic, and indeed it is rare to find studies reporting an ongoing state of anosognosia beyond the time scale of a few months. Indeed, the review paper by Orfei et al. (2007) included only anosognosia studies which were all conducted with patients maximum 80 days after trauma. A paper comparing acute and chronic conditions, found a clear drop in the frequency of anosognosia after 30 days (e.g., Pia et al., 2004).

Another observation calling for an inquiry is the lack of overall decrement in performance when evaluating d-prime cost. As noted by Sarter, Givens, & Bruno (2001), practice effects may lead to ceiling performance in target detection; in such cases, an overall increase in RT should be enough evidence for a decrease in performance over time. When considering the theoretical implications of the improvement in target detection by approximately half of the group, we would argue that these individuals simply had enough capacity of sustained attention to allow some

improvement. More compellingly so, the correlation we found between Distractibility and d-prime is much higher than any other study we are aware of, and this external validity supports our conceptualization of d-prime cost being a marker for sustained attention.

Interestingly, we only found a difference between the patient and control group when comparing the effect of a previous target trial on RTs, where the patients benefitted from a previous trial being a target but no such benefit was found for the controls group. We suggest that this effect can be attributed to group differences in phasic alertness. This is in line with the observations of Sturm and Wilmes (2001), where they attempted to find the neural substrates of sustained attention and phasic alertness. Their study concluded that phasic alertness relies on similar brain regions as sustained attention (sustained attention activated mostly a right-hemispheric frontal, parietal, thalamic, and brain-stem network), but in addition recruits left frontal parietal activity (which was unique for phasic alertness). Similar findings were observed in a recent study by Rinne and his colleagues (2013), where a reduction in Alerting indices (defined as the difference in response to target following a cue vs. no-cue) was associated with multiple regions as the bilateral anteromedial thalamus, upper brainstem, and right cerebral peduncle, as well as in several small areas across right hemisphere. In other words, phasic alertness activity seemed to correlate with more brain regions than sustained attention. Therefore, we speculate that there may consequently be a higher probability for this aspect of attention to be impaired following a brain lesion. We did not identify any specific factor from the subjective CFQ measures which correlated with what we describe as phasic alertness, whether there is a correlation relative to everyday subjective activities that reflects this, remains an open question for now.

The group difference in previous trial benefit resembles the findings by Husain and his colleagues (1997). In their study, participants had to identify two targets on a Rapid Serial Visual Presentation (RSVP) paradigm. In doing so, the researchers facilitated an “attentional blink” (AB) – a phenomenon where the identification of a second target is impaired if it follows the identification of a first target in an interval of approximately 400ms. When comparing identification of the second target in a control group and a group of patients with neglect syndrome, they discovered that the interval required to escape the AB among patients was much longer – up to 1440ms – compared with controls (Husain et al., 1997). Similar cases have also been found when testing AB with dyslectic individuals (Hari & Renvall, 2001), and with individuals suffering from Alzheimer’s disease (Kavcic & Duffy, 2003). Taking these data together, we suggest that the time intervals over which attention operates can be longer in particular clinical groups. Our findings provide further support for this by demonstrating a clear benefit for target identification in patients when the previous trial is a target-trial.

Limitations

The patient sample was unselected and included too few frontal and parietal right hemisphere damaged individuals to make any group judgements about this specific subgroup. Previous studies suggest these patients may be particularly prone to show a greater decline over time. More such patients would need to be tested on our new MCCPT to provide a further validation for the task. Second, with respect to our suggestion that a target-trial can be considered as a pre-cue and therefore a marker for phasic alertness, there is a need for further evidence. Such evidence should include a cross validation with an established task such as the Attentional Network Test (Fan et al., 2002). In addition, a systematic manipulation of the ITI between targets will allow

a more thorough examination of the cueing effect found with patients. Future research could address this question also in neurologically healthy participants, where shorter ITI manipulations may be able to elicit phasic attention indices which were not observed here. All in all, our main goal here was suggesting that phasic alertness can potentially be assessed without adding a cue to the task, and that sustained attention is better evaluated with observing the change in d-prime; such change could be facilitated by adding a visual mask between stimuli, degrading the perceptual experience.

Acknowledgements

This work was supported by a European Union FP7 Marie Curie ITN Grant (606901), the NIHR Clinical Research Facility (Oxford Cognitive Health) and the Stroke Association (TSA LECT 2015/02). We would like to thank Marleen Haupt (Ludwig Maximilian University of Munich) for assisting with data collection and Jacob Levenstein (University of Oxford) for help in delineating the lesions for the lesion overlay.

References

- Ada, L., O'Dwyer, N., Green, J., Yeo, W., & Neilson, P. (1996). The nature of the loss of strength and dexterity in the upper limb following stroke. *Human Movement Science, 15*(5), 671-687.
- Ahissar, M., & Hochstein, S. (1997). Task difficulty and the specificity of perceptual learning. *Nature, 387*(6631), 401-406. doi:10.1038/387401a0 [doi]
- Ballard, C., Stephens, S., Kenny, R., Kalaria, R., Tovee, M., & O'Brien, J. (2003). Profile of neuropsychological deficits in older stroke survivors without dementia. *Dementia and Geriatric Cognitive Disorders, 16*(1), 52-56. doi:69994 [doi]
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological), 57*, 289-300.
- Birren, J. E., & Fisher, L. M. (1995). Aging and speed of behavior: Possible consequences for psychological functioning. *Annual Review of Psychology, 46*(1), 329-353.
- Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology, 21*(1), 1-16.
- Callejas, A., Lupiáñez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition, 54*(3), 225-227.

- Chen, W. J., & Faraone, S. V. (2000). Sustained attention deficits as markers of genetic susceptibility to schizophrenia. *American Journal of Medical Genetics*, 97(1), 52-57.
- Conners, C. K., & Staff, M. (2000). Conners' continuous performance test II (CPT II V. 5). *North Tonawanda, NY: Multi-Health Systems Inc.*, 1-16.
- Corkum, V., Byrne, J. M., & Ellsworth, C. (1995). Clinical assessment of sustained attention in preschoolers. *Child Neuropsychology*, 1(1), 3-18.
- Coull, J. T. (2004). fMRI studies of temporal attention: Allocating attention within, or towards, time. *Cognitive Brain Research*, 21(2), 216-226.
- Coull, J. T., Nobre, A. C., & Frith, C. D. (2001). The noradrenergic alpha2 agonist clonidine modulates behavioural and neuroanatomical correlates of human attentional orienting and alerting. *Cerebral Cortex (New York, N.Y.: 1991)*, 11(1), 73-84.
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, 14(3), 340-347.
- Ferrucci, L., Bandinelli, S., Guralnik, J. M., Lamponi, M., Bertini, C., Falchini, M., & Baroni, A. (1993). Recovery of functional status after stroke. A postrehabilitation follow-up study. *Stroke; a Journal of Cerebral Circulation*, 24(2), 200-205.
- Fisk, A. D., & Scerbo, M. W. (1987). Automatic and control processing approach to interpreting vigilance performance: A review and reevaluation. *Human Factors*, 29(6), 653-660.

- Gao, J. H., Parsons, L. M., Bower, J. M., Xiong, J., Li, J., & Fox, P. T. (1996). Cerebellum implicated in sensory acquisition and discrimination rather than motor control. *Science (New York, N.Y.)*, 272(5261), 545-547.
- Garretson, H. B., Fein, D., & Waterhouse, L. (1990). Sustained attention in children with autism. *Journal of Autism and Developmental Disorders*, 20(1), 101-114.
- Gillebert, C. R., Humphreys, G. W., & Mantini, D. (2014). Automated delineation of stroke lesions using brain CT images. *NeuroImage: Clinical*, 4, 540-548.
- Green, D., & Swets, J. Signal detection theory and psychophysics. 1966. *New York*,
- Halperin, J. M., Sharma, V., Greenblatt, E., & Schwartz, S. T. (1991). Assessment of the continuous performance test: Reliability and validity in a nonreferred sample. *Psychological Assessment: A Journal of Consulting and Clinical Psychology*, 3(4), 603.
- Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia. *Trends in Cognitive Sciences*, 5(12), 525-532.
- Humphreys, G. W., & Riddoch, M. J. (1993). Interactions between object and space systems revealed through neuropsychology. *Attention and Performance XIV*, , 143-162.
- Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients.

- Hyndman, D., & Ashburn, A. (2003). People with stroke living in the community: Attention deficits, balance, ADL ability and falls. *Disability & Rehabilitation*, 25(15), 817-822.
- Ishigami, Y., & Klein, R. (2008). What happens to measures of alerting, orienting and executive control after 10 administrations of two versions of the attention network test? Paper presented at the *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, , 62(4) 308-308.
- Kalechstein, A., Newton, T., & Van Gorp, W. (2003). Neurocognitive functioning is associated ith employment status: A quantitative review. *Journal of Clinical and Experimental Neuropsychology*, 25(8), 1186-1191.
- Kavcic, V., & Duffy, C. J. (2003). Attentional dynamics and visual perception: Mechanisms of spatial disorientation in alzheimer's disease. *Brain : A Journal of Neurology*, 126(Pt 5), 1173-1181.
- Levene, H. (1960). Robust tests for equality of variances¹. *Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling*, 2, 278-292.
- Lim, J., & Dinges, D. F. (2008). Sleep deprivation and vigilant attention. *Annals of the New York Academy of Sciences*, 1129(1), 305-322.
- Mackworth, J. F. (1964). Performance decrement in vigilance, threshold, and high-speed perceptual motor tasks. *Canadian Journal of Psychology/Revue Canadienne De Psychologie*, 18(3), 209.

- McCrea, P. H., & Eng, J. J. (2005). Consequences of increased neuromotor noise for reaching movements in persons with stroke. *Experimental Brain Research, 162*(1), 70-77.
- Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*(3), 211-253.
- Molenberghs, P., Gillebert, C. R., Schoofs, H., Dupont, P., Peeters, R., & Vandenberghe, R. (2009). Lesion neuroanatomy of the sustained attention to response task. *Neuropsychologia, 47*(13), 2866-2875.
- Müller, H. J., & Humphreys, G. W. (1991). Luminance-increment detection: Capacity-limited or not? *Journal of Experimental Psychology: Human Perception and Performance, 17*(1), 107.
- Nebes, R. D., & Brady, C. B. (1993). Phasic and tonic alertness in alzheimer's disease. *Cortex, 29*(1), 77-90.
- Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin, 89*(1), 133.
- Oken, B., Salinsky, M., & Elsas, S. (2006). Vigilance, alertness, or sustained attention: Physiological basis and measurement. *Clinical Neurophysiology, 117*(9), 1885-1901.
- Orfei, M. D., Robinson, R. G., Prigatano, G. P., Starkstein, S., Rusch, N., Bria, P., . . . Spalletta, G. (2007). Anosognosia for hemiplegia after stroke is a multifaceted phenomenon: A systematic review of the literature. *Brain : A Journal of Neurology, 130*(Pt 12), 3075-3090. doi:awm106 [pii]

- Parasuraman, R. (2000). *The attentive brain* The MIT Press.
- Parasuraman, R., Mutter, S. A., & Molloy, R. (1991). Sustained attention following mild closed-head injury. *Journal of Clinical and Experimental Neuropsychology*, 13(5), 789-811.
- Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, 35, 73-89. doi:10.1146/annurev-neuro-062111-150525 [doi]
- Pia, L., Neppi-Modona, M., Ricci, R., & Berti, A. (2004). The anatomy of anosognosia for hemiplegia: A meta-analysis. *Cortex*, 40(2), 367-377.
- Posner, M. I. (2008). Measuring alertness. *Annals of the New York Academy of Sciences*, 1129(1), 193-199.
- Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review*, 78(5), 391.
- Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology*, 79(1p2), 1.
- Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience*, 7(5), 367-379.
- Rinne, P., Hassan, M., Goniotakis, D., Chohan, K., Sharma, P., Langdon, D., . . . Bentley, P. (2013). Triple dissociation of attention networks in stroke according

to lesion location. *Neurology*, 81(9), 812-820.

doi:10.1212/WNL.0b013e3182a2ca34 [doi]

Robertson, I. H. (2001). Do we need the “lateral” in unilateral neglect? spatially nonselective attention deficits in unilateral neglect and their implications for rehabilitation. *Neuroimage*, 14(1), S85-S90.

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(6), 747-758.

Robertson, I. H., Mattingley, J. B., Rorden, C., & Driver, J. (1998). Phasic alerting of neglect patients overcomes their spatial deficit in visual awareness. *Nature*, 395(6698), 169-172.

Robertson, I. H., Ridgeway, V., Greenfield, E., & Parr, A. (1997). Motor recovery after stroke depends on intact sustained attention: A 2-year follow-up study. *Neuropsychology*, 11(2), 290.

Robertson, I. H., Tegnér, 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.

Roca, J., Castro, C., López-Ramón, M. F., & Lupiáñez, J. (2011). Measuring vigilance while assessing the functioning of the three attentional networks: The ANTI-vigilance task. *Journal of Neuroscience Methods*, 198(2), 312-324.

- Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: Where top-down meets bottom-up. *Brain Research Reviews*, 35(2), 146-160.
- Schmidt, E. A., Schrauf, M., Simon, M., Fritzsche, M., Buchner, A., & Kincses, W. E. (2009). Drivers' misjudgement of vigilance state during prolonged monotonous daytime driving. *Accident Analysis & Prevention*, 41(5), 1087-1093.
- Shalev, L., Ben-Simon, A., Mevorach, C., Cohen, Y., & Tsal, Y. (2011). Conjunctive continuous performance task (CCPT)—A pure measure of sustained attention. *Neuropsychologia*, 49(9), 2584-2591.
- Shalev, L., Kolodny, T., Shalev, N., & Mevorach, C. (2015). Attention functioning among adolescents with multiple learning, attentional, behavioral, and emotional difficulties. *Journal of Learning Disabilities*, , 0022219415579125.
- Shuell, T. J. (1986). Cognitive conceptions of learning. *Review of Educational Research*, 56(4), 411-436.
- Sturm, W., De Simone, A., Krause, B., Specht, K., Hesselmann, V., Radermacher, I., . . . Willmes, K. (1999). Functional anatomy of intrinsic alertness: Evidence for a fronto-parietal-thalamic-brainstem network in the right hemisphere. *Neuropsychologia*, 37(7), 797-805.
- Sturm, W., & Willmes, K. (2001). On the functional neuroanatomy of intrinsic and phasic alertness. *Neuroimage*, 14(1), S76-S84.
- Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics*, 49(1), 83-90.

- Tyler, L. K., Chiu, S., Zhuang, J., Randall, B., Devereux, B. J., Wright, P., . . . Taylor, K. I. (2013). Objects and categories: Feature statistics and object processing in the ventral stream. *Journal of Cognitive Neuroscience*, 25(10), 1723-1735.
- Wallace, J. C., Kass, S. J., & Stanny, C. J. (2002). The cognitive failures questionnaire revisited: Dimensions and correlates. *The Journal of General Psychology*, 129(3), 238-256.
- Weinbach, N., & Henik, A. (2011). Phasic alertness can modulate executive control by enhancing global processing of visual stimuli. *Cognition*, 121(3), 454-458.
- Yanaka, H. T., Saito, D. N., Uchiyama, Y., & Sadato, N. (2010). Neural substrates of phasic alertness: A functional magnetic resonance imaging study. *Neuroscience Research*, 68(1), 51-58.

Table 1: Brief overview of the lesion descriptions for the patients included. M= male, F= female; R = Right; L = Left; MCA = Middle Cerebral Artery. Brain scans were not available for patients #10 and #15, and patient #12 did not have any visible lesion in the clinical scan. In these cases the lesion descriptions were based on the medical notes from the admitting hospital.

ID	Sex	Dominant Hand	Lesion Description
#01	F	R	Right Frontal, Parietal Occipital
#02	M	R	Left Frontal, Temporal, Insular, Bilateral Subcortical
#03	F	R	Left Cerebellum
#04	M	R	Left Occipital
#05	M	R	Left Insular, Subcortical
#06	M	R	Right Frontal, Insular, Cerebellum
#07	F	R	Left Cerebellum
#08	F	R	Left Occipital
#09	M	R	Right Cerebellum
#10	M	R	Right Insular, Subcortical
#11	M	R	Left Temporal, Precuneus
#12	M	L	No visible lesion (medical note: right MCA territory)
#13	M	R	Left Brain Stem, Right Precuneus
#14	F	R	Left Insular, Frontal, Parietal, Occipital
#15	M	R	Left Frontal
#16	M	R	Bilateral subcortical
#17	M	R	Left Occipital
#18	M	L	Right Frontal, Insular, Subcortical
#19	M	R	Left Cerebellum, Occipital
#20	M	R	Left Subcortical
#21	M	L	Bilateral Occipital, Temporal
#22	F	L	Bilateral Occipital, Cerebellum
#23	M	L	Left Frontal, Temporal, Insular, Parietal, Occipital, Subcortical

Table 2: Inter-correlations of the CFQ factors

	<i>Distractibility</i>	<i>Memory</i>	<i>Blunders</i>	<i>Naming</i>
<i>Distractibility</i>	1			
<i>Memory</i>	.709**	1		
<i>Blunders</i>	.467**	.636**	1	
<i>Naming</i>	.246	.360*	.438**	1

*p<.01; **p<.001

Table 3: Descriptive Statistics of performance on the MCCPT task for both the patient and the control group.

	<i>RT-STD</i>	<i>Mean RT</i>	<i>Omissions</i>	<i>Commissions</i>	<i>d'</i>	<i>Criteria</i>
<i>Controls</i>	94ms	525ms	2.5%	2%	4.33	0.05
<i>Patients</i>	120ms	548ms	5%	3%	3.83	0.1

Table 4: A correlation matrix of the three outcome measures for assessing sustained-attention

	<i>RT-STD</i>	<i>d'</i>	<i>d'-cost</i>
<i>RT-STD</i>	1		
<i>d'</i>	-0.339**	1	
<i>d'-cost</i>	-0.082	0.132	1

**p<.01; critical values adjusted according to Benjamini & Hochberg, 1995

Table 5: Descriptive statistics of the group performance

	<i>Control (Mean, SE)</i>	<i>Patients (Mean, SE)</i>
<i>RT-STD</i>	93.21 (5.67)	157.76 (28.26)
<i>d'</i>	4.28 (0.09)	3.43 (0.28)
<i>d'-cost</i>	-0.12 (.07)	-0.19 (.13)

Table 6: A correlation matrix between CFQ factors and sustained attention indices

	<i>Distractibility</i>	<i>Memory</i>	<i>Blunders</i>	<i>Naming</i>
<i>RT-STD</i>	-.152	-.058	.092	.153
<i>d'</i>	.305	.253	.165	.043
<i>d'-cost</i>	.600*	.354*	.253	.161

*p<.01; **p<.001; critical values adjusted according to Benjamini & Hochberg, 1995

Figure Captions

Figure 1. Lesion overlay for 19 patients out of the 23 patients: Four patients were omitted from the lesion overlay. One scan was not available, one scan had no visible lesion and two patients were excluded from the analysis based on their performance (patients #21 and #22; see results section). Patients' anatomical scans were manually delineated slice-by-slice, by a trained research technician. The binary delineation was performed using MRIcron (McCausland Center for Brain Imaging, Columbia, SC, USA). Once the lesion masks were generated, a 5mm full width at half maximum (FWHM) smoothing was applied in the Z-direction. Patients' anatomical scans were linearly registered to a standard template space (i.e., MNI152_T1_2mm) and the resulting registration matrix from this transform was then applied to the binary lesion mask. The processing of the scans and registration was performed using SPM8 (the Wellcome Trust Centre for Neuroimaging, London, United Kingdom) and custom MATLAB scripts (The Math Works, Natick, MA, United States) consistent with the methods described in Gillebert, Humphreys, & Mantini (2014). All patient lesion masks were concatenated to create a conjunction map where intensity values represent the number of patients with a lesion in a given coordinate (max overlay of sample is 4).

Figure 2. a) Illustration of the alternating mask; b) Schematic experimental outline;

Figure 3. Group averages of reported symptoms in the CFQ (error bars represent Standard Error)

Figure 4 (a). Average RT over three blocks - thirds - of the session trials (error bars represent Standard Error) (b) Average RT over three blocks - thirds - of the task (error bars represent Standard Error)

Figure 5. N-1 effect on reaction times for controls and patients (error bars represent Standard Error)

Figure 6: A scatter plot for the correlation between d-prime cost and Distractibility factor. Line represents linear fit correlation = .6

Figure 1

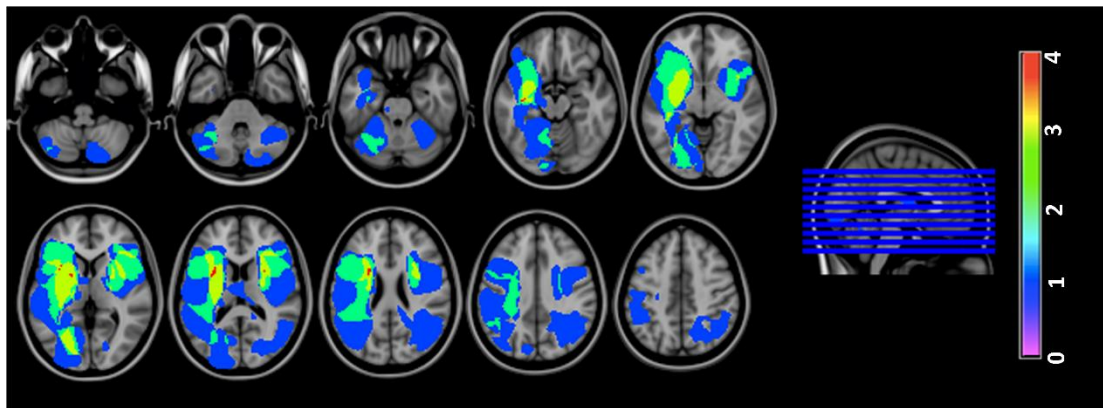


Figure 2

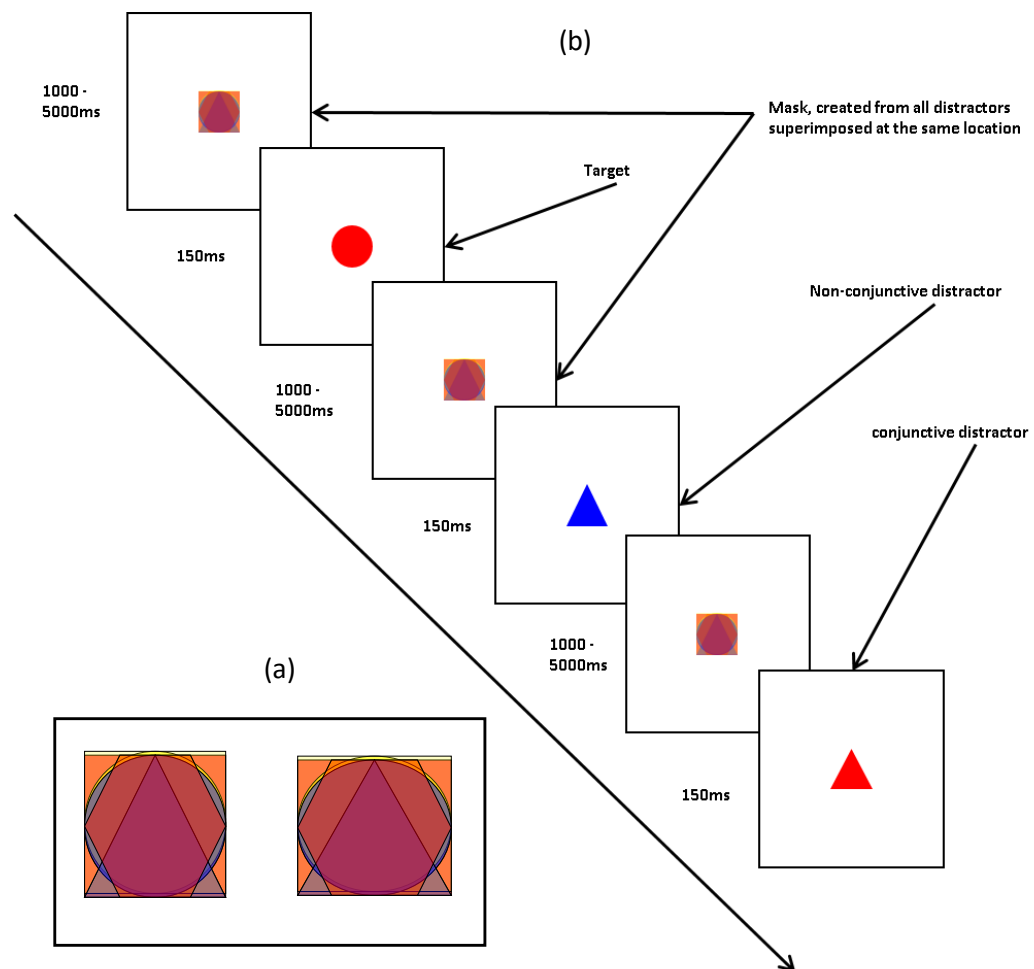


Figure 3

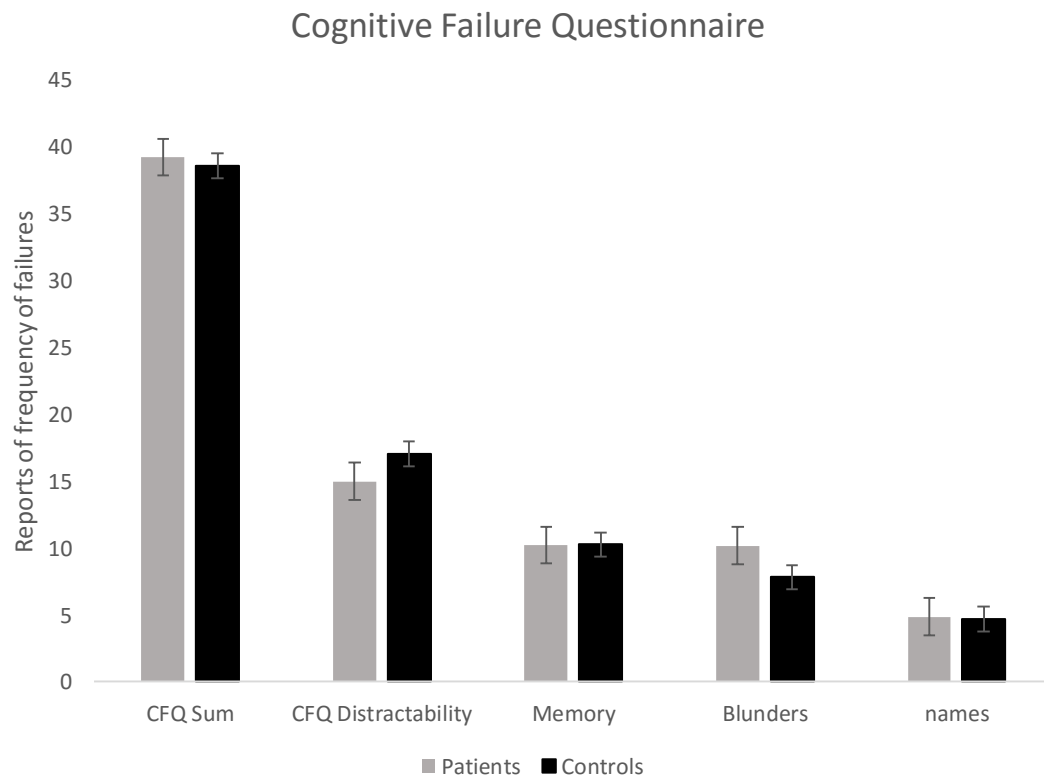
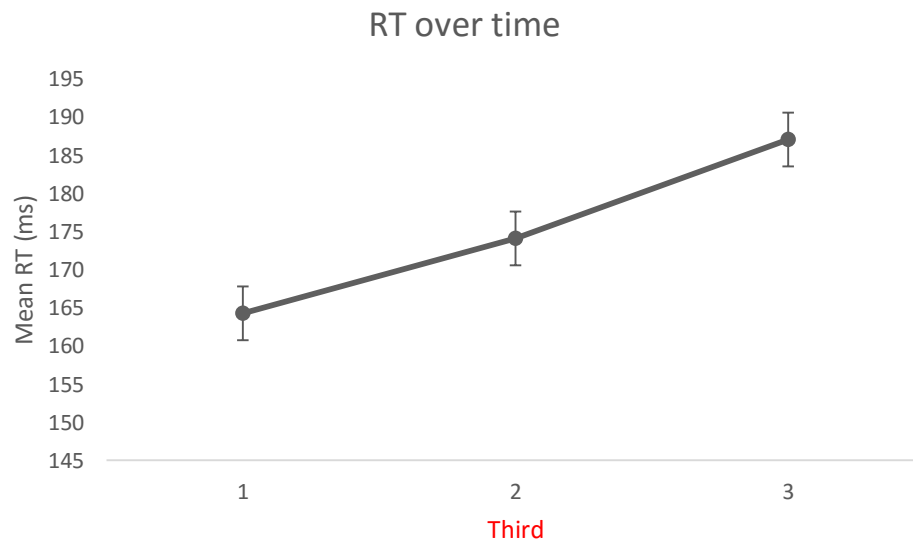
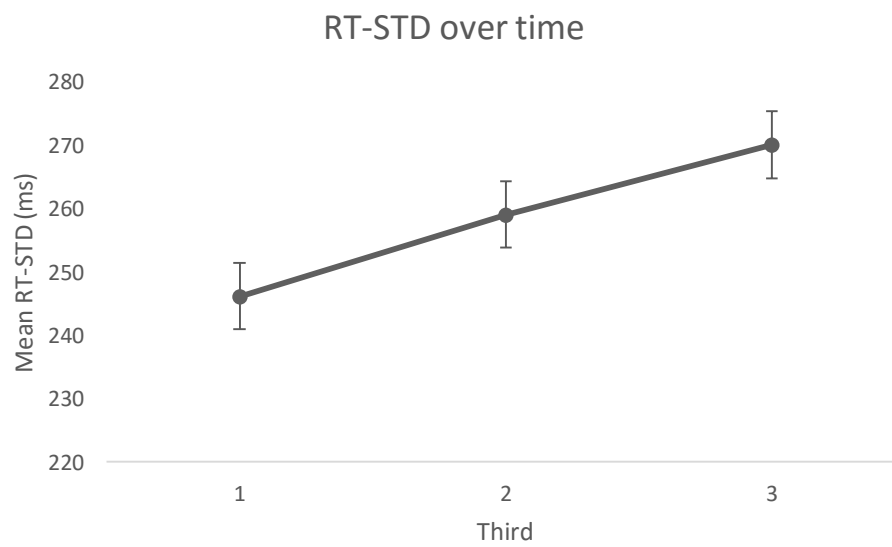


Figure 4



(a)



(b)

Figure 5

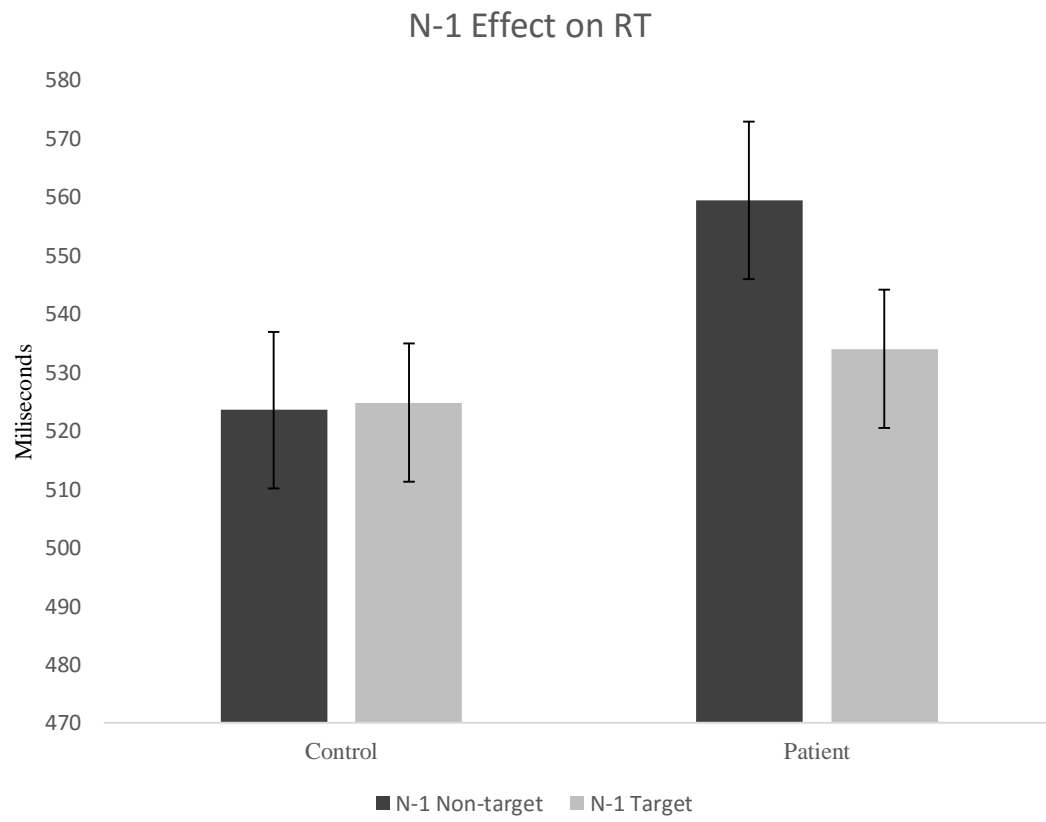


Figure 6

