Assessing lapses of attention in sleep disorders

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ABSTRACT
While sustained wakefulness is a necessary condition for complex human behaviors such as driving, all too often occupational environments tolerate performance at levels of attention which are suboptimal for responses to the rare and unexpected contingencies associated with accident and injury. In some people vulnerabilities for impaired attentional performance are innate as a result of medical illness. This paper details the clinical assessment of attention deficits using a simple test of sustained performance in a population of people with sleep disorders. Our findings suggest that approximately 75% of clinical sleep disorders patients exhibit deficits of sustained attention beyond the range of healthy people and that these deficits have no consistent association with self-assessments of “sleepiness”.

INTRODUCTION
The consequences of impaired attention are substantial. In Sweden, annual costs from accidents attributed to sleepiness exceed 1.7 billion kronor and result in over 1.6 million lost work-days. Driver fatigue is associated with up to 30% of all motor vehicle accidents. Independently of sleep, failures of attention have been implicated in 48% of car accidents [1]. Tellingly, 20% of vehicle fatalities occur in traffic intersections. And for every accident that occurs, imperfect attention fosters between 3000 and 40,000 potential accidents (depending on severity)[2].

While each of us has likely suffered the discomfort of maintaining alertness and attention from inadequate sleep, for many, sleep disturbances are chronic. 32% of the Swedish population report frequent non-restorative sleep and 10% daytime fatigue [1]. One common sleep disorder in particular, sleep apnea, has been associated with highly increased risks for motor vehicle accidents risks in numerous studies [2]. This paper details the clinical assessment of the functional capacity to maintain attention in individuals who may be particularly vulnerable to impaired alertness and attention during wakefulness and are therefore at higher risk for accident and injury. This paper details the clinical assessment of the functional capacity to maintain attention in patients with sleep disorders and complaints of excessive sleepiness and fatigue during wakefulness.

The risks and burdens of sleep disorders can be conceptualized using an iceberg metaphor (figure 1). While states of undesired sleep and drowsiness are most obvious to those experiencing them and to those nearby, breakdowns in attention and impairments of the efficiency of attention and other cognitive processes required for optimal and safe performance are more difficult to perceive and to observe. By virtue

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of their stealth and greater exposure over the course of the waking day, deficits of attention contribute to a major public health hazard.

The objective of our laboratory is to assess a person's functional capacities to maintain arousal (i.e., wakefulness) and attention during wakefulness. The clinical patients whom we evaluate are referred with complaints of excessive daytime sleepiness and/or fatigue which impact the quality of their lives and integrity of their work. The majority of these people have been previously diagnosed with sleep disorders, most commonly sleep apnea, and many are under treatment.

**METHODS**

Our laboratory assessments of clinical patients and research subjects employ a series of 4 short (20-30 minute) tests are administered once during the morning and then repeated in the afternoon. On the night prior to each evaluation, the quantity and integrity of sleep patterns (usually at home) are documented using a portable data recorder (Embla A10, Flaga Reykjavik). Each test is designed to probe unique aspects of neurocognitive function including: sustained attention, complex visual information processing, psychomotor performance and the maintenance of arousal/wakefulness. This paper will detail the first of these – the ability to recruit and sustain attention in a stimulation-poor environment.

**Subjects**

Our clinical population sample (n = 115) is comprised of patients (median age 46 years, Inter Quartile Range 39:56) with sleep disorders and compromised daytime alertness. The majority suffer from sleep apnea. Normal controls (n=12, median age 35, IQR 24:49).

**Gosling test of simple attention**

The maintenance of attention is assessed over a 20 minute test period by presenting low intensity visual stimuli on an LCD computer display for 1 second at random intervals between 3 and 10 seconds (Gosling test). Subjects are instructed to respond as soon as they detect each stimulus by pressing a button. In order to minimize extraneous arousal, the subjects are tested sitting up in a comfortable bed, in a darkened room, and without any indications of time or their performance.

The Gosling is implemented on a Windows-XP/PC platform using programs developed for the DMDX psychophysiological experiment software [3]. The subject response button is a sensitive 2-paddle Morse-code key which requires minimal physical pressure and a lateral finger movement of only 0.1 mm to activate. DMDX measures response times with 1 millisecond accuracy. If no response is made within 2 seconds of the onset of the stimulus, the trial is identified as a missed response or “lapse”. If more than 1.5 minutes of continuous sleep are detected in the concurrent EEG recording, the test is aborted and the subject is awoken in order to prevent the effects of a “recovery nap” on subsequent tests.

The outcome measures from the Gosling are derived from 1) the speed of the subject's response to the onset of the stimulus (reaction time, RT) and 2) the occurrence of lapses.
Physiology
Brainwaves (EEG), heart activity (EKG), eye movements (EOG) and respiration are recorded during testing in order to verify wakefulness, detect drowsiness and microsleep-episodes, and examine cardiovascular responses.

Subjective alertness and arousal
Daytime sleepiness is assessed using the self-report Epworth Sleepiness Scale (ESS) [4]. The ESS is an 8-item questionnaire which asks the likelihood of falling asleep in common situations (e.g., sitting on a sofa or as a car passenger). Perceptions of fatigue, which is characterized by tiredness or exhaustion, without necessarily being related to sleepiness, are measured using the Swedish translation of the 30-item Fatigue Impact Scale (FIS) [5],[6]. Both of these scales are retrospective and reflect generalized “trait-like” self perceptions of life experiences. In order to query aspects of well being under testing, subjects rate their perceptions of alertness, sleepiness, stress, difficulty fighting sleep, task difficulty and their task performance using a visual analog scale (VAS) after each test trial.

Statistics
The processing and statistical analyses of all study data are performed using software written in the R statistical language [7]. Analyses of lapse occurrences are made using general estimating equation regression models (GEE) with Poisson links and are reported by the robust Z statistic (the ratio of effect /error variance) and associated P value.

CLINICAL OUTCOMES
Patients with sleep disorders exhibit considerable heterogeneity in their ability to sustain attention under testing although only approximately 25% perform within the expectations for healthy control subjects (fig 3. We have observed that patients with poor attentional performance fall into 1 of 2 general patterns. Most commonly seen are sporadic and short-term lapses without any evidence of sleep or drowsiness in the EEG record. Over the course of the 20 minute test, these lapses often recur at progressively shorter intervals. The second pattern is associated with sleep and drowsiness and is characterized by relatively long lapse periods (i.e., consecutive missed responses) and slowed response times. Figure 3 is representative of the predominant pattern of response behaviors in patients complaining of daytime fatigue and sleepiness. Breakdowns in attention manifest as failures to respond to isolated stimulus trials (lapses), usually without corresponding sleep or slowing of reaction times.

Lapses
Typically, and in even the most severe cases, the response performance of subjects is good within the first 5 to 10 minutes of testing. In impaired subjects, lapses then emerge with varying frequency and durations. Figures 4a and 4d illustrate the cumulative counts of lapses and the

Table 1: Percentage of missed trials by study group (Median and interquartile ranges (IQR))

<table>
<thead>
<tr>
<th>% missed trials</th>
<th>median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>0.6 (0 : 1.5)</td>
</tr>
<tr>
<td>sleep disorder</td>
<td>4.0 (1 : 21)</td>
</tr>
</tbody>
</table>

Figure 3: Distributions of lapse prevalence by study group. Note x-axis log scaling.
time intervals between lapse occurrences. The differences in the distributions of lapses between patients and normal control subjects are illustrated in figure 3 and table 1. As is evident from figure 3, the variability of lapse severity among patients is considerable. Although approximately 25% are within the expected ranges for normal controls (~2 missed trials), the remainder of patients have unambiguous deficits.

**Response reaction times**

Response reaction times over the 20 minute test are shown in figure 4d with a superimposed “trend” as well as a boxplot summary. Occurrences of missed responses are shown in the “rug” along the bottom time line. Lapse periods are seldom accompanied by a generalized slowing of reaction times.

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**Figure 4: Example Gosling test summary from one patient.** (a) Running cumulative number of lapses. (b) Histogram of consecutive missed responses. (c) Response reaction times with robust average. (d) Time intervals between successive lapses (log scale). Note the breakdown of sustained attention with the onset of lapses after approximately 10 minutes with the onset of lapses.
Relationships between subjective ratings of fatigue and sleepiness and Gosling lapses

Figure 5: Scatter plots of ESS (daytime sleep propensity) scores and 2 measures of stimulus response efficiency with marginal boxplots. This figure illustrates the insensitivity of the ESS to detect attention related deficits in our sleep disordered cohort.

Global “trait” ratings of daytime sleep propensity using the ESS ratings did not predict attention performance (Z 1.2, P 0.2) (figure 5). Global ratings of fatigue using the FIS, on the other hand, did predict attention (Z 2.6, p. 0.01). Among the VAS ratings administered at the end of each test, “difficulty fighting sleep” (Z 2.2, p. 0.03) was more discriminative than “alertness” (Z -1.8, p. 0.07)

DISCUSSION

In our experience, many patient with sleep disorders exhibit deficits in the maintenance of attention over even short challenge periods (< 20 minutes). These deficits manifest chiefly as “lapses” - failures to detect and respond to “simple” stimuli.

In contrast to overt drowsiness and sleep, attentional lapses often manifest as transients superposed on a background of efficient responses. This highlights the challenges of detecting and predicting them in operational environments and of evaluating their potential risks they entail. In operating environments like cars, life and death or injury often hang in the balance of responses that need to be made in the blink of an eye. At 90 km/hr (56 MPH), a car travels 25 meters in 1 second and with a 3 degree deviation of the steering wheel, that car travels 12 meters laterally in 3 seconds. Even with ideal responses under good conditions, a freeway bound car requires a minimum of 75 meters to come to a stop. We often take the gamble for several seconds and a hundred or more meters of highway to tune the radio or dial the cell phone when we don't expect contingencies. We may tolerate sleepiness or lack of focus behind the wheel with little regard or awareness for the consequences of not being able to react optimally to that rare and unexpected event. But as traffic conflict analyses reveal, contingencies do occur continuously on the road and avoiding them is often a matter of statistical probability and luck. In Sweden every year,
luck runs out for approximately 460 drivers who fail to detect and avoid large animals (predominantly moose) on the road. These accidents result in over 80 (human) deaths and serious injuries [8].

In addition to the Gosling, full diagnostic workups in our lab include a test of higher level cognitive functions related to the processing of complex visual information (attention network test), psychomotor tracking (continuous tracking task) and the ability to maintain wakefulness under conditions of minimal stimulation (MWT). While these provide a comprehensive view of an individuals functional capabilities related to attention, hard evidence of which directly links objective test performance with historical or prospective risks (e.g., diminished occupational performance or car accidents) is lacking. Future population studies which examine associations between precognitive status and incident histories or current measures of driver performance from automated vehicle data will be helpful in this regard. Less directly, there is evidence of an association between the common sleep disorder apnea and motor vehicle accident risk [9], however the diagnosis of sleep apnea alone is not specific enough for a clinician to identify “high risk” cases which may call for occupational and driving restrictions. The challenge for functional assessments remains to reliably detect and predict impairments and to inform appropriate treatment.

We have found objective measures to be particularly helpful in cases where patient self reports have been influenced by motivations to either minimize or accentuate the extent of their symptoms.

In conclusion, assessments of attention using the Gosling have proven valuable in our practice for validating the presence of gross deficits of attention, particularly in cases where self reports have been influenced by motivations to either minimize or accentuate the extent of their symptoms. People with sleep disorders and excessive daytime fatigue have a substantial likelihood of having a reduced capacity to maintain simple attention over a 20 minute test period and suggest these functional impairments create opportunities for increased safety risks. We encourage greater public awareness and continued public-health policy initiatives [9] directed towards the safety issues posed by sleep disorders.

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REFERENCES


