Specific attention disorders in drivers with traumatic brain injury

MARJOLAINE MASSON1, GEORGE ANDREW MICHAEL1, JEAN-FRANÇOIS DÉSERT2, FRANÇOIS RHEIN2, LUCIE FOUBERT2, & PASCALE COLLIOT1

1EMC Laboratory (EA 3082), University of Lyon 2, France, and 2Physical Medicine and Rehabilitation Centre, Coubert, France

(Received 24 February 2012; revised 11 October 2012; accepted 8 January 2013)

Abstract
Objective: To highlight the impact of the increasing attentional load on performance of both normal drivers and drivers with traumatic brain injury.
Background: Patients with brain injury have a higher accident risk than people with no brain injury [1], probably as a result of persistent attention disorders.
Method: Ten patients and 10 paired controls took part in a computerized selective attention task involving specific attentional processes. They were asked to monitor a speedometer and to ignore sudden changes in the surrounding environment in three separate experimental situations involving different attentional load.
Results: Although, in the control situation, patients' results were equivalent to controls', they displayed specific disorders in more complex situations where the attentional load increased.
Conclusion: These difficulties may have a negative impact on real driving situations.

Keywords: Attention disorders, attentional load, attentional processes, traumatic brain injury, driving

Introduction
Traumatic Brain Injury (TBI) is the most frequent disease of the central nervous system and is frequently caused by motor vehicle collisions. After TBI, disorders vary and include neurological and/or neuropsychological impairments, such as, inter alia, information processing, memory, executive function and attentional disorders. Since these neuropsychological abilities are specifically involved in driving, drivers with TBI could be unsafe [1].

In brain damaged patients, stopping driving has been linked to employment difficulties, a higher incidence of depression, poor social integration, and an inability to engage in activities outside the home [2]. It is one of the most functionally disabling consequences of TBI [3]. An estimated 40–80% of patients with TBI with varying degrees of cognitive impairment return to driving after their injury [4], often without any formal assessment of their driving ability [5, 6]. In patients with severe TBI the risk of motor vehicle crashes is 2.3 times higher than in people without TBI [1]. The question is whether some of the attention processes involved in driving could be at least partly responsible for such crashes.

This study looks specifically at such attentional processes. Drivers' lack of attention has frequently been cited as a major cause of motor vehicle accidents. Several different aspects of attention are required for driving, but divided attention, which...
involves carrying out more than one task at a time, has commonly been deemed relevant to driving capacity [7], given that several sources of information have to be attended to at once (e.g. speedometer, movements of the car in front) and people frequently drive and do something else at the same time (e.g. smoke, eat/drink, fiddle with the radio, chat with a passenger or on the phone). However, people’s attentional resources are seemingly limited [8]. Attention must, therefore, be divided between several tasks and the amount of resources available for each task is bound to decrease. Studies have shown that such dual-tasking diverts attention and impairs driving performance. For instance, Strayer et al. [9] conducted a study in which healthy participants were asked to brake as quickly as possible when the car in front was braking. In a dual-task condition, where they had to brake and engage in conversation at the same time, their reaction time (RT) was higher than when they were not required to drive and talk at the same time. According to the authors, the explanation for this was that conversation could represent a distraction during driving.

Attention defects while driving have been known following TBI, and Van Zomeren and Van den Burg [10] demonstrated residual complaints some 2 years after TBI. Such cognitive impairments are a real hindrance to socioprofessional rehabilitation and cause difficulties in daily life. There is no consensus about specific attention deficits due to TBI, but researchers agree that one of the most common complaints is difficulty performing two tasks simultaneously, a difficulty which increases with the complexity of the task [11–13]. No neuropsychological tests are fully predictive and totally sensitive [14], which makes it difficult to highlight attention disorders during driving, especially minor ones, that are reported by the population with TBI. The purpose of this study was, therefore, to test patients with minor or not clearly established diagnosed attention disorders, as assessed with conventional neuropsychological tests. They might be patients without attention disorders but who experience attentional difficulties in daily life (e.g. problems concentrating, doing two things at once, etc.) or patients only with disturbances in fewer attentional processes. These patients were tested by asking them to perform a computerized task involving various specific attentional processes independently of each other. The attentional processes required to perform this task are well known to be essential in driving activity. In a visual selective attention task participants were required to monitor a speedometer and to ignore sudden changes in the surrounding environment (change in the position of the car in front) in three situations: a silent situation, a situation with the radio on and a situation involving active conversation. It was hypothesized that the performance of both controls and patients with TBI would decrease as the attentional load increased, that patients would have attention disorders compared to controls and that this gap would widen as the attentional load of the task increased. It was predicted the task would reveal a drop in performance linked to a distraction (‘radio’ situation) and even more so in a dual task (‘conversation’ situation), because of bad management of the available attentional resources.

Method
Participants
Ten males who had suffered a TBI and 10 control participants (matched in age, gender and educational level) with no history of neurological impairment took part in the present study. Each patient was paired up with a control participant. They all had a driving licence. The average age of the patients was $35.46 \pm 16.3$ years (range 19.2 to 61.2), compared to $34.3 \pm 16.9$ years (range 18.1 to 63.2) for the controls. Their mean level of education was $12.8 \pm 8.5$ years for the patients and $12.7 \pm 3.7$ years for the controls. The profile details of the patients with TBI (Glasgow Coma Scale, age, years of study and time elapsed since TBI) are presented in Table I. The patients with TBI were all tested between 2 and 19 months after their injury (mean 9.3 months) and recruited from the Physical Medicine and Rehabilitation Centre (PMRC) in Courbet, France. The control group included people who represent the general population. They were recruited in the hospital: in patients circle, care staff

<table>
<thead>
<tr>
<th>Patients with TBI</th>
<th>GCS</th>
<th>Age (years)</th>
<th>Level of education (years)</th>
<th>Months since onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>15</td>
<td>59.8</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>P2</td>
<td>15</td>
<td>48.8</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>P3</td>
<td>6</td>
<td>61.2</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>P4</td>
<td>13</td>
<td>21.1</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>P5</td>
<td>13</td>
<td>28.9</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>P6</td>
<td>12</td>
<td>20.6</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>P7</td>
<td>7</td>
<td>40.8</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>P8</td>
<td>6</td>
<td>19.2</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>P9</td>
<td>/</td>
<td>33.1</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>P10</td>
<td>7</td>
<td>21.1</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Mean $\pm SD$</td>
<td>10.5 $\pm 3.9$</td>
<td>35.5 $\pm 16.4$</td>
<td>12.8 $\pm 2.4$</td>
<td>9.3 $\pm 6.8$</td>
</tr>
</tbody>
</table>

GCS = Glasgow Coma Scale; / = no data available; SD = Standard Deviation.
or administrative staff. The patients were not diagnosed with any psychiatric disorder and none of the controls had any history of neurologic or psychiatric disorder (i.e. attention deficit hyperactivity disorder). Moreover, none of them had diagnosable substance abuse or comprehension disorder. All of the participants had normal or corrected-to-normal vision and all gave their written consent. This test was part of a comprehensive neuropsychological assessment.

Procedure

Materials. The experimental protocol was computerized and run on a PC (HP Pavilion zv 6000) with a 15.4 inches screen. A computer was used instead of a driving simulator in order to avoid simulator sickness, to use a handy tool, easier to implement in hospitals and also because the environment of a computer is simpler than that of a simulator and, consequently, more easy to control.

During the test, participants were asked to imagine being inside a car. On the screen they were shown a landscape (in several shades of grey) including a road with bushes on both sides (Figure 1). On the road they could see the rear view of a car (as if the car was in front of them on the same road). In the foreground was a speedometer, as if they themselves were also in a car. The speed changed regularly, increasing or decreasing every 500 milliseconds (30 km/h minimum to 70 km/h maximum) in a random and totally unpredictable fashion. The random changes in speed shown on the speedometer were irregular so that they could not be anticipated. These random speedometer changes were done to incite subjects to perform the selective attention task at optimal levels by preventing them from predicting the arrival of a target. Since the participants could not predict the differences in speed, they would be more sensitive to the changes in the surrounding environment.

Procedure. Before the experiment and for patients with TBI only, attention processes were assessed with some conventional neuropsychological tests. The Stroop colour-word interference task [15] was used to examine the conflict between one well-learned or automatic behaviour (reading) and a decision rule that requires this behaviour to be inhibited. Participants are required to read 100 black colour words (word card), to name the colours of 100 solid squares (colour card) and to name

![Figure 1. Car's position.](image)
Attention and driving

Concerning the first variable, the car in front could adopt one of three possible positions (Figure 1): ‘far’, ‘near’ or ‘intermediate’. The sudden change in the car’s position could be perceived as a car’s phi movement in two positions: in the ‘far’ position the car moved away from the participant, in the ‘near’ position it moved towards the participant. In the ‘intermediate’ position it maintained a constant speed and, thus, its position remained unchanged. In this intermediate position, the car’s tail lights came on to ensure that an effect of ‘near’ and/or ‘far’ position would be due not simply to an overall change in picture compared to the intermediate position, but to the car’s position. All three car positions occurred randomly and equiprobably. The ‘intermediate’ position was considered as the baseline. The change of the car’s position could enhance the attentional load, except in the ‘near’ position. Indeed, according to Franconeri and Simons [18], the alerting could be produced by looming stimuli as opposed to receding stimuli. The change in position of the car in front coincided with the appearance of the target (30 or 70 km/h) and then could act as an alert when the car is looming. In every condition, half of the targets corresponded to the speedometer at 30 and the other half to the speedometer at 70. The target identity (30 or 70) was random in each new trial. Distractors (i.e. speeds other than 30 and 70) were presented between successive targets, with their number chosen at random. The target/distractor ratio was one to six. All the participants performed the experiment in three situations with an increasing attentional load gradient: (a) ‘silent’, where the experimenter was present during the task but did nothing, (b) ‘radio’, where the experimenter fiddled with the radio throughout the task, and (c) ‘conversation’, where the experimenter was engaged in active conversation with the participant during the task. The ‘silent’ situation was a control situation (without additional attentional load). In the ‘radio’ situation, all the participants were confronted with the same auditory stimulus, pre-recorded on an audio cassette (a recent and commonplace newsflash), and they were asked not to pay any attention to the stimulus. The attentional load in this situation is higher than in the ‘silent’ situation because participants had to inhibit the radio. In the ‘conversation’ situation, conversation took the form of a semi-directive interview consisting of several standard questions about family, cinema, literature, itineraries, etc. The questions deliberately required long answers to increase the demands placed on participants’ attention. Consequently, this is the most costly situation. The three situations were

the colours of 100 incongruent colour words (colour-word card) as fast as possible.

The D2 focused attention test [16] was used to measure processing speed, rule compliance and quality of performance, allowing estimation of individual attention and concentration performance. The items are composed of the letters ‘d’ and ‘p’ with one, two, three or four dashes arranged either individually or in pairs above and below the letter. The subject is given 20 seconds to scan each line and mark all ‘d’ with two dashes and inhibit distractor (i.e. ‘d’ with one or more than two dashes and all ‘p’). There are 14 lines of 47 characters each.

Finally, several sub-tests of the Test of Attentional Performance (TAP) [17] were chosen: the phasic alerting and the divided attention sub-tests. The first one allowed assessing the ability to increase the attentional level when a stimulus of high priority is likely to appear. The task consists of two conditions; in both, participants have to react as quickly as possible to a visual stimulus (a cross). In condition A, participants are only presented a visual stimulus. However, in condition B, shortly prior to the visual stimulus, an auditory warning signal is presented. The alertness reaction is defined as the difference between condition A and B.

The divided attention sub-test (TAP) allowed assessing the capacity to do two things simultaneously. This is done by a visual and an auditory task. In the visual task participants see a display of 16 points (four in each row and column). Some of these points change to crosses and participants have to press the response button as soon as four of those crosses form a small square. The auditory task consists of an alternating sequence of high and low tones; participants have to press the response button when they detect an irregularity in the sequence. The task was conducted in three blocks: (a) visual stimuli only (single task), (b) auditory stimuli only (single task) and (c) visual and auditory stimuli together (dual task). The performance of patients in the different tests was compared to the norm.

Patients began the experiment just after the neuropsychological assessment. All the participants were seated 60 cm in front of the screen, with the index finger of their dominant hand on the spacebar of a standard computer keyboard. They were asked to monitor the speedometer by hitting the spacebar when the speed was equal to 30 km/h or 70 km/h. The reason for asking them to detect these two targets was to enhance the attentional difficulty of the task. They were asked to respond as quickly and as accurately as possible because the computer would record their response time.

During the task, the attentional load could be varied in two ways: by controlling the position of the car ahead and by controlling the experimental situation (silent, radio or conversation).
balanced across participants in a Latin square order. Participants completed a set of 20 trials per car position per situation, in other words a total of 180 trials per participant. Each experimental situation took 5 minutes and the total test (including instructions) lasted approximately 20 minutes.

**Results**

Patients with TBI were assessed with several standardized neuropsychological tests known to involve different attentional processes: Stroop (to assess the interference), TEA (included two sub-tests: phasic alert and divided attention) and D2 (to assess the rhythm and errors rate). Hence, scores lower than 2 SD (standard deviation) were considered pathological. The results of the neuropsychological assessment showed that, compared to the norm, 2/10 patients with TBI had difficulties inhibiting stimuli (pathological score in the Stroop test), 2/10 had difficulties with selective attention (rhythm D2), 1/10 had a pathological score in the phasic alert test and 5/10 in the divided attention test (Table II). Consequently, half of the patients in this study had divided attention disorders, a finding in keeping with the literature [11].

Concerning the computerized experiment, an analysis of variance was performed with the software Statistica 5.0 on mean correct RTs, with the position of the car in front (near, far, intermediate) and the three situations (silent, radio, conversation) as within-participant factors and the group of participants (patients with TBI and control participants) as the only between-groups factor. The main effect of group was significant \( F(1, 18) = 7.68; p < 0.0126 \). Patients (mean = 537 ms, SD = 121 ms) were slower than control participants (mean = 458 ms, SD = 79 ms). The main effect of the position of the car in front was significant \( F(2, 36) = 20.22; p < 0.0001 \), such that both patients and controls had lower RTs in the ‘near’ position (mean = 468 ms, SD = 83 ms) than in the ‘intermediate’ (mean = 514 ms, SD = 112 ms) and ‘far’ positions (mean = 512 ms, SD = 125 ms). The analysis also revealed a significant interaction between the position of the car and the group of participants \( F(2, 36) = 4.48; p < 0.0183 \) (Figure 2). Multiple contrasts revealed a significant effect of the vehicle’s position only for patients, with the difference between the ‘near’ and ‘intermediate’ positions higher for patients than controls (patients mean: 63 ms; controls mean: 29 ms; \( p < 0.0157 \)). There was a similar difference between the ‘near’ and ‘far’ positions (patients mean: 68 ms; controls mean: 20 ms; \( p < 0.0118 \)).

The analysis also revealed a significant effect of the situation independently of the other manipulated factors \( F(2, 36) = 35.70; p < 0.0001 \), revealing higher RTs in the ‘conversation’ situation (mean = 575 ms, SD = 133 ms) than in both the ‘silent’ (mean = 457 ms, SD = 59 ms) and ‘radio’ situations (mean = 461 ms, SD = 77 ms). This effect was different for each group, insofar as the situation \( \times \) group interaction was significant \( F(2, 36) = 4.53; p < 0.0176 \) (Figure 3), such that

![Figure 2. Interaction between the car’s position and the group patients with TBI/controls.](image-url)

Table II. Neuropsychological assessment of patients with TBI.

<table>
<thead>
<tr>
<th>Patients with TBI</th>
<th>Stroop: interference^a</th>
<th>D2: rhythm^b</th>
<th>D2 (P%)</th>
<th>TEA: Phasic Alert^b</th>
<th>TEA: Divided Attention^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>95</td>
<td>18.4</td>
<td>0</td>
<td>86</td>
<td>54</td>
</tr>
<tr>
<td>P2</td>
<td>116</td>
<td>61.8</td>
<td>5.87%</td>
<td>42</td>
<td>69</td>
</tr>
<tr>
<td>P3</td>
<td>209*</td>
<td>/</td>
<td>/</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>P4</td>
<td>138*</td>
<td>9.7*</td>
<td>7.8%</td>
<td>38</td>
<td>4*</td>
</tr>
<tr>
<td>P5</td>
<td>122</td>
<td>21.2</td>
<td>9.37%</td>
<td>46</td>
<td>4*</td>
</tr>
<tr>
<td>P6</td>
<td>72</td>
<td>13.6</td>
<td>2.7%</td>
<td>96</td>
<td>18</td>
</tr>
<tr>
<td>P7</td>
<td>74</td>
<td>69.2</td>
<td>8.35%</td>
<td>24</td>
<td>34</td>
</tr>
<tr>
<td>P8</td>
<td>79</td>
<td>21.2</td>
<td>3.7%</td>
<td>27</td>
<td>&lt;1*</td>
</tr>
<tr>
<td>P9</td>
<td>79</td>
<td>21.2</td>
<td>0.47%</td>
<td>18</td>
<td>4*</td>
</tr>
<tr>
<td>P10</td>
<td>110</td>
<td>4.5*</td>
<td>0</td>
<td>8*</td>
<td>&lt;1*</td>
</tr>
</tbody>
</table>

^aPathological score (\( p < 0.05 \)); ^b in seconds; ^c in percentile rank; /= no data available.
the difference between the ‘silent’ and ‘conversation’ situations was greater for patients than controls (patients mean: 165 ms; controls mean: 71 ms; \( p < 0.0089 \)). Regarding the comparison between the ‘silent’ and ‘radio’ situations, the difference tended to be greater for patients than controls (patients mean: 20 ms; controls mean: –12 ms; \( p < 0.0775 \)).

Moreover, post-hoc Newman-Keuls tests showed a significant difference between controls and patients in the ‘radio’ situation \( (p < 0.0210) \). With the radio on, patients (mean = 495 ms, SD = 75 ms) were slower than controls (mean = 427 ms, SD = 62 ms). The fact that patients took longer to respond than controls could not be explained by a general slowing, given that there was no significant difference between the two groups in the ‘silent’ situation (patients mean: 476 ms; controls mean: 438 ms; \( p > 0.1059 \)). The difference between the ‘radio’ and ‘conversation’ situations was also greater for patients than controls (patients mean: 145 ms; controls mean: 83 ms; \( p < 0.0489 \)).

The last result involved a three-way interaction including all the variables: the group of participants, the position of the car, and the different situations \( [F(4, 72) = 2.95; p < 0.0258] \) (Figure 4). In patients, compared with controls, the effect of the preceding vehicle’s position (advantage for the ‘near’ position) was more pronounced in the ‘radio’ situation \( (p < 0.0494) \) and even more so in the ‘conversation’ situation \( (p < 0.0238) \). Moreover, the negative effect of conversation for patients was less in the ‘near’ position than in the ‘intermediate’ and ‘far’ positions \( (p < 0.0001) \). Lastly, when studying the interaction between the position of the car and the three situations for each group separately, a significant interaction was found only for patients \( [F(4, 36) = 6.83; p < 0.0003] \).

In addition to the ANOVA, three indices were calculated, representing three attentional processes involved in the experimental task: (a) phasic alerting, defined as the performance increment in the presence of a warning signal. The phasic alerting index was calculated by subtracting the RTs in the ‘near’ position from those observed in the ‘intermediate’ position. According to Franconeri and Simons \[18\], ‘alerting’ is produced by looming stimuli as opposed to receding stimuli, with the creation of an apparent looming motion as the car in front loses its lead over the car behind. The aforementioned results showed that looming served as a warning signal since RTs were shorter than in

![Figure 3](image1.png)

**Figure 3.** Interaction between the situation and the group of participants patients with TBI/controls.

![Figure 4](image2.png)

**Figure 4.** Interaction between the three variables: the group of participants, the car’s position and the situation.
the other positions; (b) distraction, defined as the interference produced by an irrelevant signal during processing of a target. The distraction index was calculated by subtracting mean RTs in the ‘silent’ situation from those obtained in the radio situation. The presence of an irrelevant auditory signal can interfere with target processing in the visual task and, therefore, increase RTs; and (c) divided attention, defined as the ability to perform two concurrent tasks correctly. The divided attention index was calculated by averaging RTs obtained in the ‘radio’ and ‘silent’ situations and then subtracting this mean from the mean RT obtained in the ‘conversation’ situation. The ‘silent’ and ‘radio’ situations are both single tasks, whereas the conversation situation is a dual task which involves dividing attention between the visual task and the conversation. The divided attention index enabled one to calculate the dual task cost by comparing the results in the dual task situation (‘conversation’) with those obtained in the neutral situation (‘silent’) and the situation with surrounding noise (‘radio’). The results are presented in Table III.

Using the Student test, each patient was compared to the control group for each index. Eight out of 10 patients had phasic alerting that was significantly higher than that of controls. Six out of 10 patients (but not always the same ones as for the previous index) had more difficulty than controls in dividing their attention between two tasks performed simultaneously. Lastly, six out of 10 patients were more easily distracted than controls.

**Discussion**

One of the main aims of the study was to highlight attentional changes in both controls and drivers with TBI via a computerized task involving several attentional components that are known to be essential in driving. Initially it was hypothesized that this task would reveal a drop in performance linked to the increasing attentional load. To check the hypothesis, performance was studied in a visual selective attentional task (monitoring the speedometer) which could be carried out with the addition of an irrelevant visual change in the surroundings (position of the car ahead) and/or with a second task that was more or less demanding in terms of attention (passive listening to radio or active conversation). It was expected that the performance of both controls and patients would decrease as the attentional load increased (i.e. with some specific changes in the surrounding environment, in the presence of a distractor and when faced with dual tasking). A bigger drop in performance was also expected for patients than controls.

These results showed that patients with TBI were generally slower than controls, but that the slowdown occurred only in the presence of an additional distracting auditory signal (radio) or when dual tasking was required (conversation during the visual task). The slowdown was greater when the attentional load increased, in other words in the ‘conversation’ situation. This slowdown is well-known as a disorder encountered in patients with TBI [19]. Ponsford and Kinsella [13] showed that patients with severe TBI had slower reaction times than controls in simple and dual tasks alike. In this study, however, the slowdown was observed only when there was a sizeable attentional load (in the dual task). This is probably due to the fact that half of the patients had moderate or mild TBI. Consequently, in line with the findings of Ponsford and Kinsella [13], it is entirely plausible that only patients with severe TBI experience a general cognitive slowdown.

These results revealed a simple effect of the position of the car in front. According to expectations, participants were quicker to respond when the car was nearer. It is important to point out that the position of the car’s tail lights were on. It can, therefore, be presumed that the effect observed when the car in front was near (reduction in RTs) was due not to a simple change in the picture, but to the position of the car. A looming stimulus would result in a quicker response due to an automatic orientation of attention (orientation reflex). However, according to Posner [20], a basic attention mechanism (phasic alerting) is involved in preparing drivers to react to expected signals when warnings are provided. The change in the position of the car in front accelerated performance and can clearly be interpreted as a phasic alerting effect. The sudden change in the vehicle’s position could

---

**Table III. Index of phasic alert, distraction and divided attention (in milliseconds).**

<table>
<thead>
<tr>
<th>Patients with TBI</th>
<th>Phasic alert (in ms)</th>
<th>Distraction (in ms)</th>
<th>Divided attention (in ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>62.53*</td>
<td>8.19*</td>
<td>146.24*</td>
</tr>
<tr>
<td>P2</td>
<td>54.53*</td>
<td>-3.23*</td>
<td>232.75*</td>
</tr>
<tr>
<td>P3</td>
<td>24.53</td>
<td>88.47*</td>
<td>55.15*</td>
</tr>
<tr>
<td>P4</td>
<td>77.60*</td>
<td>52.81*</td>
<td>296.67*</td>
</tr>
<tr>
<td>P5</td>
<td>47.30*</td>
<td>35.67*</td>
<td>145.92*</td>
</tr>
<tr>
<td>P6</td>
<td>43.42*</td>
<td>-2.05*</td>
<td>88.70</td>
</tr>
<tr>
<td>P7</td>
<td>53.16*</td>
<td>-5.28*</td>
<td>86.97</td>
</tr>
<tr>
<td>P8</td>
<td>31.61</td>
<td>51.20*</td>
<td>46.53*</td>
</tr>
<tr>
<td>P9</td>
<td>70.59*</td>
<td>-40.43*</td>
<td>157.27*</td>
</tr>
<tr>
<td>P10</td>
<td>166.58*</td>
<td>12.39*</td>
<td>293.41*</td>
</tr>
</tbody>
</table>

Mean ± SD (patients) 63.19 ± 39.81* 19.77 ± 37.26* 155 ± 92.01*  
Mean ± SD (controls) 29 ± 20.73 -11.54 ± 8.78 76.91 ± 32.53  

*Pathological score ($p < 0.05$); SD = standard deviation.
be perceived as movement and participants could use the movement of the car as a warning signal since the two targets (30 and 70 km/h) coincided with the movement. Why this effect was not apparent when the car moved far away is unclear. Franconeri and Simons [18] showed that attention can be captured by a stimulus in motion, although this does not happen with all dynamic events. With their experiment they were able to show that attentional capture occurs only with looming stimuli and not receding stimuli and they used this finding to develop the behavioural urgency hypothesis, according to which priority will only be given to an event requiring urgent action. In this study, the car’s approach, rather than its distancing, could have been given priority as corresponding to a sudden expansion of a surrounding stimulus and, therefore, synonymous with danger. That explains why there is a quicker response to a stimulus that is closer. However, there is another explanation for this result. According to Van Zomeren and Brouwer [21], the phasic alert is more quantitative than qualitative. As the car approached, the number of pixels on the screen increased and, with it, the salience, showing brighter colour greys; conversely, as the car moved away there were less pixels and, with it, less salience, showing dimmer colour greys. As the alert is determined by intensity and contrast, it would be more pronounced the greater the salience, that is to say in the ‘near’ position.

Both of these hypotheses are interesting, but the first one (the looming explanation) would appear to be more in keeping with the authors’ own opinion. It is thought that the danger-based explanation involves phasic alert and is indirectly linked to a driving context. With driving, all looming stimuli constitute obstacles and are, therefore, a road hazard that drivers have to avoid. Consequently, with many everyday activities, such as driving, people are used to reacting as quickly as possible when confronted with looming stimuli. Moreover, alert is a primitive phenomenon and a process shown to be robust by the fact that it is often unimpaired following a TBI [22].

Nevertheless, this effect was greater in the case of patients than controls, as shown by the analysis of the phasic alerting indices. This may be a sign that processes like prior enhancement of target-related signals and the control of preparation for action are defective [20]. Over-reactivity to the warning stimulus may, therefore, reflect a dysfunction of phasic alerting, as has been observed following release from motor inhibition [23]. Insofar as motor inhibition is related to the frontal lobe [24], this pattern of results is not unexpected in patients with TBI [23]. The monitoring task results showed that 8/10 patients were over-reactive compared to controls (Table III), whereas only one patient had a phasic alerting disorder in the neuropsychological test (Table II). Over-reactivity could be dangerous during driving because patients with TBI need only to select relevant information and not react to every stimulus around them. For example, some advertisement displays are attractive (changing or luminous) and could be a distraction for patients with TBI. It is, therefore, fair to suppose that, when faced with attractive stimuli, these patients may have difficulty staying focused on the road.

The results of the ANOVA confirmed the prediction about an effect of situation. RTs were expected to increase with the attentional load. In other words, they were expected to increase in the presence of auditory distractive signals (radio) and in dual task conditions (conversation) as compared to the ‘silent’ situation. In both situations the hypothesis was shown to be correct.

In the light of other studies carried out in a more ecological way [26, 27], it was shown that the ‘radio’ situation had no impact on control participants’ performance. In their case the attentional load associated with listening to radio was not sufficiently substantial and they were able to inhibit the radio and perform the monitoring task. With patients, a drop was observed in their performance in the radio situation compared to controls (see distraction index). It is likely they were bothered more by this increasing load than controls, as compared with the ‘silent’ situation. In this study, listening to radio was not relevant for the monitoring task and represented a distractor that participants have to inhibit. These findings were in keeping with those of Vakil et al. [25], who proposed an inhibitory processes disorder after TBI or, more specifically, that patients have difficulty inhibiting distractors. The neuropsychological assessment also included an inhibition test (Stroop) which showed that only 2/10 patients had difficulty (Table II), whereas the result in the computerized experiment was much higher (6/10 patients had difficulty, Table III). The difference in results may be due to the fact that the monitoring task was more complex or involved a higher attentional load. It is true that in the monitoring task the visual scene was more elaborate than in the Stroop test, as well as involving movement (the car in front), cues and distractors and, sometimes, the added distraction of the radio or conversation. Finally, 8/10 patients passed the inhibition test but displayed disorders in a more complex task (monitoring task), hence the importance of including attentional load in the assessment.

In the ‘conversation’ situation, participants (controls and patients) were slower to respond, in keeping with the study by Strayer and Johnston [27] who observed a disruptive effect of conversation, but
no effect of listening to the radio. A slowdown in dual tasking was also observed in the literature with a cell phone conversation [9]. Given that attentional resources are limited [8], using them for conversation means they are less available for the main visual task. As assessed via attention indexes, the cost of dual tasking was greater for most patients than controls, a finding consistent with several studies which have suggested that patients with TBI suffer from divided attention disorders [11, 28–30], although there is no consensus as to the underlying mechanisms. Contrary to the multiple resource theory [31], the results showed that even if the two tasks performed concurrently involve different sensorial resources (visual and auditory), the multitasking is not possible without a drop in performance. The auditory task (‘conversation’) affected performance in the visual task (monitoring the speedometer). The handling of the two tasks was less efficient in the dual task than in the ‘silent’ situation. One is therefore able to hypothesize that the driving performance of both groups (patients and controls) may be affected in a dual task context. However, patients had more difficulty than controls in the dual task situation. Driving is a multi-task activity: talking with a passenger while driving, for example, is a common occurrence and, yet, could be dangerous for people, such as persons with TBI, who have divided attention disorders. The attentional resources available to patients for processing the surrounding environment while driving are reduced when they engage in conversation. Contrary to Azouvi et al. [11], it is suggested that patients with TBI failed to manage the attentional resources efficiently and did not allocate attention according to priorities.

To summarize, concerning the experimental situations (silent, radio and conversation), a gradual drop was identified in performance as the attentional load increased. Moreover, this attentional gradient effect was more pronounced for patients than controls. Patients are more sensitive to attentional load insofar as the ‘radio’ situation already has an impact on performance of participants with TBI but not on that of controls.

Otherwise, a movement in the surrounding environment (car ahead in motion) could improve participants’ performance in some conditions involving an alerting process (‘near’ position). This process is known to be unimpaired after TBI [22].

Lastly, it is noted that for patients the negative effect of the conversation situation decreased when the car was close. The looming motion of the car alerted patients with TBI (their RTs decreased) and allowed them to reduce their divided attention deficit. Combined with the visual task, the conversation situation is a difficult dual task which is very demanding in terms of attention and divided attention is seemingly altered in this sample of participants with TBI. However, patients benefitted from alerting to recover such a disorder, the suggestion being that their divided attention disorder can be attenuated if their attention is drawn towards salient stimuli. Indeed, as the car approached participants had to respond, such that they were alerted and the attentional processes simplified, leaving more attention available for the dual task.

One can assume that if there was no ‘near’ position in the experimental procedure the conversation effect (drop in performance) would be greater and consequently the gap between patients and controls wider.

Attention disturbances may have an impact on driving competence. However, it is possible to compensate for the difficulties. The elderly have attentional disorders which do not necessarily affect real driving competence [7]. The same mechanisms may conceivably be involved for people with TBI. According to Brouwer [7], patients with TBI may use compensation mechanisms so that they are more fit to drive. For example, they may drive more slowly so they have more time to processing the information about the road. The problem is that some patients with TBI are anosognosic. They are not aware of their disturbances and consequently cannot compensate for them in daily life, as the accident rate showed for patients with TBI [1].

Conclusion

This study suggests that patients with TBI have attentional difficulties which increase with the attentional load and controls have a decrease of attentional efficiency in some high attentional load condition. Patients experience more difficulties than controls, which suggest the management of attentional resources is disturbed following a TBI. As the attentional load increased, patients with TBI exhibited (a) slowed information processing, insofar as they took longer to perform the task than controls, (b) greater distractability and (c) difficulty dividing their attention between two concurrent tasks. They also over-reacted to warning signals, which reduces the dividing attention trouble. These three deficits may have a negative influence on their overall driving performance, since all of these aspects of attention and, especially divided attention, are required for driving. Even over-reactivity could affect driving performance. It could mean they react to all stimuli, even those that are irrelevant. In this study, the ‘near’ position always occurs in conjunction with a target (relevant stimulus). This study suggests a complex context (high attentional load) is needed to
assess attention disorders in drivers with TBI. Consequently, it is important to use suitable tasks for detecting attentional troubles and having an opinion about road safety of patients who resumed driving after a TBI. The assessment of fitness to drive is a current research field. However, the question of drive safety is relevant.

Acknowledgements

We would like to thank all the participants for taking part in the study.

Declaration of Interest: The authors report no conflicts of interest. This research study was supported by two Region Rhône-Alpes/France grants (Cluster 11-2009/2010 and CIBLE 2010), a LABEX Cortex grant and doctoral funding.

References