

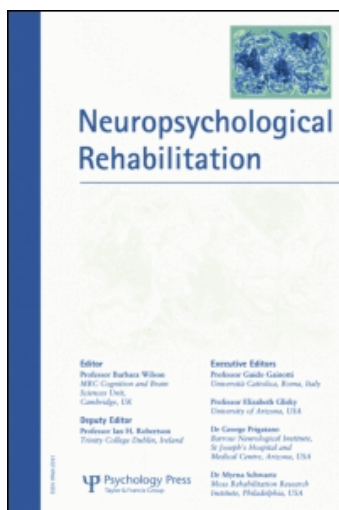
This article was downloaded by: [Vrije Universiteit, Library]

On: 20 March 2011

Access details: Access Details: [subscription number 907218019]

Publisher Psychology Press

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Neuropsychological Rehabilitation

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713684225>

### Mental Fatigue after Very Severe Closed Head Injury: Sustained Performance, Mental Effort, and Distress at Two Levels of Workload in a Driving Simulator

H. Riese

Online publication date: 22 October 2010

**To cite this Article** Riese, H.(1999) 'Mental Fatigue after Very Severe Closed Head Injury: Sustained Performance, Mental Effort, and Distress at Two Levels of Workload in a Driving Simulator', *Neuropsychological Rehabilitation*, 9: 2, 189 — 205

**To link to this Article:** DOI: 10.1080/713755600

**URL:** <http://dx.doi.org/10.1080/713755600>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

## **Mental Fatigue after Very Severe Closed Head Injury: Sustained Performance, Mental Effort, and Distress at Two Levels of Workload in a Driving Simulator**

H. Riese<sup>1</sup>, M. Hoedemaeker<sup>2</sup>, W.H. Brouwer<sup>3</sup>, L.J.M. Mulder<sup>3</sup>,  
R. Cremer<sup>4</sup>, and J.B.P. Veldman<sup>3</sup>

<sup>1</sup> *Vrije Universiteit, Amsterdam*; <sup>2</sup> *Delft University of Technology, Delft*;  
<sup>3</sup> *University of Groningen, Groningen*; <sup>4</sup> *Institute TNO Work & Employment, Hoofddorp, The Netherlands*

In patients with very severe closed head injury (CHI), returning to work is often problematic. The present study focuses on a persistent complaint of these patients, viz. mental fatigue. To study this, the effect of sustained workload is assessed in a continuous dynamic divided attention task. Three types of measures are employed: performance loss with time-on-task, and subjective reports and cardiovascular measures of mental effort and distress. Eight very severe CHI patients (mean post-traumatic amnesia duration 51 days, mean age 23 years, (SD 6.4) and eight hospital controls (mean age 29 years, (SD 5.9) were tested. No differences were found between the patients and controls in the effects of task load on performance and the amount of mental effort, even in very demanding simulated work conditions. This parallels previous findings in less demanding laboratory tasks of sustained attention. Effects of CHI were found on both subjective and physiological indicators of distress. Compared to the controls, patients showed stronger effects on systolic blood pressure and subjectively experienced load.

---

Requests for reprints should be sent to H. Riese, Vrije Universiteit, Dept. of Biological Psychology, De Boelelaan 1111, 1081 HV Amsterdam, The Netherlands. Telephone: +31-20-4448822, telefax: +31-20-4448832, email address: h.riese@psy.vu.nl.

A short version of this study (poster) was presented at the 6th TENNET conference at the Université de Québec à Montréal, 1995 (Brouwer et al., 1996). The authors would like to thank the Rehabilitation Clinic Heliomare, Wijk aan Zee, The Netherlands, for providing the facilities to perform the experiment. Peter Van Wolffelaar is thanked for his extensive help in programming the simulator task. Lorenz Van Doornen is thanked for his comments on an earlier draft of the manuscript. Conor Dolan is thanked for checking on the English language.

Traumatic brain damage often leads to persistent mental impairments that may interfere with everyday activities such as work and education (Brooks et al., 1987; Minderhoud & Van Zomeren, 1984; Richardson, 1990). Particularly in very severe cases, returning to work has been found to be problematic (Brooks et al., 1987; Oddy, 1984; Van Zomeren & Van Den Burg, 1985). Brooks et al. (1987) and Oddy (1984) studied return to work 2–7 years after patients had suffered severe and very severe concussions and found 50–60% of the patients had lost their jobs. Also many patients were unable to work at their former capacity.

Neuropsychological tests often fail to demonstrate impairments in such patients. One explanation for this failure is that these tests require concentration only for a short period of time, and permit recovery between test sessions (Van Zomeren & Brouwer, 1994). Furthermore, these tests only measure actual performance, but not the subjective and psychophysiological costs involved. As a result, important causal factors concerning problems with return to work may be overlooked. The purpose of the present study is explicitly to investigate this issue by testing patients on sustained, highly demanding, simulated real-life tasks, and by assessing performance as well as the subjective and psychophysiological costs involved.

The most common type of traumatic brain damage is closed head injury (CHI), in which primary brain damage results mainly from movements of parts of the brain relative to each other and to the skull base. Secondary damage may result from complications in the first days after injury (Richardson, 1990). If the impact leads to a loss of consciousness for longer than approximately one minute, the resulting condition is called CHI or concussion. The most frequently used indicator of severity is the duration of post traumatic amnesia (PTA) which includes coma duration. According to the well-known Russell classification (Russell, 1971), severe concussion is indicated by a PTA lasting from one day up to one week, and very severe concussion by a PTA exceeding one week. Van Zomeren and Van Den Burg noted (1985) an increasing frequency of problems in returning to work in persons with a PTA duration exceeding 13 days. Therefore, the present study concentrates on patients with a PTA duration of 14 days and over.

In the literature, several predictors of the ability to return to work following concussion have been proposed. In the field of neuropsychological testing of cognitive function, Crépeau and Scherzer (1993) found measures of the integrity of executive functions to be the best predictors. However, according to Van Zomeren and Brouwer (1994) impairment of executive functions is not a very common sequel in less severely impaired cases which constitute the greater proportion of CHI victims. More common sequelae are memory impairment and slowed information processing (Ponsford & Kinsella, 1989; Van Zomeren, Brouwer, & Deelman). In their meta-analysis on the other hand, Crépeau and Scherzer (1993) found only weak relationships between the presence of these

latter impairments and the inability to return to work. Also physical impairments, such as hemiparesis, did not play a significant role. So there appears to be an unexplained discrepancy between the relatively low percentage of patients with severe neuropsychological impairment and the 50–60% drop-out reported by Oddy (1984) and Brooks et al. (1987).

This discrepancy may imply the existence of important mental sequelae of closed head injury which are relevant to everyday cognitive function but which are missed by current neuropsychological assessment. Our approach to this area is a psychophysiological one, aimed at mental fatigue and related symptoms. A different approach is chosen by Robertson and coworkers (1997) who developed a test of short-term sustained attention which may indicate an aspect of executive function not measured well by existing test methods and shown to be correlated moderately highly with everyday slips of attention both after CHI and in healthy controls.

Mental fatigue has received little attention in neuropsychological research, presumably because adequate objective measures are lacking. The importance of this category in work-related rehabilitation was already noted by Luria (1963 p. 244) who observed that “fatigue” was the principal obstacle to the training of patients with sequelae of closed head injuries and post-concussional states”. The category of mental fatigue comprises complaints of decreased mental stamina, i.e. tiring very easily when engaging in mental activities, irritability, and an increased frequency of headaches. Such complaints are mentioned by up to 70% of CHI patients (McKinlay et al., 1983; Oddy, Humphry, & Uttley, 1978). In contrast to the cognitive symptoms, these complaints are reported as frequently in mild, severe, and very severe CHI patients. This suggests that they are not directly related to the brain damage. Van Zomeren et al. (1984) argued that these complaints are due to the constant compensational effort required in meeting the demands of a normal life following CHI. This is also known as the coping hypothesis. Compared to the most severe CHI patients the pressure to perform at the pre-injury level may be higher in less severe CHI patients. One factor could be a greater awareness of impairment in the less severe CHI patients. A second factor could be a larger social pressure to resume responsibilities because the impairments are less obvious to others. It follows that mental effort and experienced distress due to higher psychophysiological costs, during and after sustained task performance, are important variables to study.

The coping hypothesis is the starting point for the present experimental study of the effects of a moderate and a high level of sustained mental workload on performance, mental effort, and experienced distress. Sustained performance is measured in terms of the loss of speed and accuracy as a function of time-on-task. Mental effort and distress are assessed using self-report and cardiovascular measures obtained before, during, and after sustained effort.

An extensive account of the relationship between mental effort, distress, and the cardiovascular system is given by Mulder and Mulder (1981; Mulder, 1986;

Mulder et al., 1992). Normally, people react to sustained heavy task demands by an initial stress reaction, which is called the defence reaction. This reaction is supposed to be caused by a general activation of the sympathetic nervous system and inhibition of the vagal system; accompanying classical cardiovascular reactions are an increase in blood pressure and heart rate (HR) and a decrease in heart rate variability (HRV). Mulder (1980) argued that the best available cardiovascular index for the amount of invested mental effort is the rest-task difference in the 0.07–0.14 Hz band of HRV (see also Aasman, Mulder, & Mulder, 1987; Mulder & Mulder, 1981 for further explanation). The defence reaction is accompanied by subjective experience of mental effort which is required for stable task performance. With the cardiovascular regulation theory (Van Roon, 1998) it can be explained how, after 10–15 minutes, homeostatic processes overrule this initial stress reaction; blood pressure, HR, and HRV display initial strong reactions but are brought within normal limits. These homeostatic processes regulate the blood pressure around a given set point. High levels of blood pressure are tolerable for short periods of time, for example when immediate action (“fight or flight”) is required, but should not become chronic. Research findings in our laboratory support that this cardiovascular reaction pattern to task load is not exclusively determined by mental effort. Longer-term regulation mechanisms also appear to be involved in blood pressure regulation. In a healthy population, Mulder et al. (1992) showed that blood pressure decreases continuously over a 45-minute work period after an initial strong baseline task increase of more than 20 mmHg. Hard mental work for a longer period of time may evoke changes in cardiovascular state. In this case the state variables, like blood pressure, do not return to their normal baseline values. Subjectively, this state is characterised by changes in mood (e.g. irritability) and of physical discomfort (e.g. tension, headache) (Veldman, 1992; Veldman et al., in press).

Two versions of the coping hypothesis may be considered. In the first version it is expected that if cognitive impairment is compensated for by means of decreasing the task demands to a level which is better suited to the cognitive capacities, the effects of sustained workload on mental effort and distress should be similar in CHI patients and control subjects. In the second version of the hypothesis, which forms the basis of the present study, it is expected that even when task difficulty is adapted to the cognitive capacities of CHI patients increased effort and distress will be found in this group. This distinction has both theoretical and practical significance. If the symptoms of mental overload and distress do not show when the cognitive demands on patients are reduced to suit their cognitive capacities, a specific brain-damage related explanation need not be expected. If, on the other hand, an additional vulnerability to (work) stress is present, even when mental load is adjusted, this phenomenon requires a specific explanation. This finding would have important implications for rehabilitation and reintegration in work and education.

In previous studies, Brouwer (1985) and Brouwer and Van Wolffelaar (1985) found no differences in time-on-task performance over a period of 15 minutes or more in a sustained attention task between CHI patients and control subjects and this was also the outcome of many subsequent studies (see however Manly & Robertson, 1997; Whyte et al, 1995). In their experiments Brouwer and Van Wolffelaar (1985) also assessed mental effort during task performance with a cardiovascular measure, viz. HRV in the 0.07–0.14 Hz band. They did not find any task-related differences between the groups on this variable either. However, in their experiments, the work period was relatively short and the tasks were relatively undemanding, only one cardiovascular measure of mental effort was used, and no distinction was made between mental effort and distress. In the present study the issues of sustained performance and mental fatigue were re-examined with a more adequate design involving longer and more demanding work and a more complete assessment of mental effort and distress.

So, the question addressed is whether severe CHI patients are more vulnerable to (work) stress than a control group. Work stress was operationally defined as one hour sustained performance in a dual-task at 50% or 80% of individual maximum capacity. Three types of dependent variables were distinguished: performance measures, short-term measures of mental effort, and long-term measures of distress following sustained mental effort. Mental effort and distress were operationalised both in terms of subjective judgement, and in terms of cardiovascular variables. Based on the literature discussed in this introduction, we expected that even though task requirements are individually adapted, the CHI group would still show more signs of distress.

## METHOD

### Participants

Sixteen men participated in the experiment: eight with very severe CHI and eight without a central nervous disorder. All had been seriously injured by an accident, and had required rehabilitation. The two groups were demographically matched on sex, age, and educational level but not on IQ, because IQ may be influenced by severe CHI. IQ was measured using the GIT (Groninger Intelligentie Test, a Dutch IQ test; Luteijn & Van Der Ploeg, 1983). The GIT includes a standard Dutch 7-point scale for measuring educational level, ranging from primary school (1) to university level (7). The mean age of the control group was 28.9 years (SD 5.9), mean education level was 4.9 (SD 1.0), and mean IQ score was 119 (SD 9.5). The mean age of the CHI group was 23.3 years (SD 6.4), mean education level was 4.9 (SD 1.3), and mean IQ score was 106 (SD 15.3). The mean length of coma duration of the CHI group was 18.4

days (range = 2–45 days). The mean PTA duration was 51.1 days (range = 14–77 days). The CHI group was selected from a group of more than 200 CHI patients hospitalised in a rehabilitation clinic in the past 3 years prior to the experiment. Participants were selected for invitation on the basis of the information provided in their hospital records. Participants complied with three criteria: (1) no documented focal lesions, (2) PTA duration of 14 days or more, and (3) the accident that caused the CHI had to be at least 9 months previously.

Exclusion criteria for both groups were: (1) a diagnosis of dementia, aphasia, or apraxia or any other severe cognitive disability that could interfere with testing, (2) diagnosis of psychiatric or neurological disorders preceding or following the accident (e.g. depression or epileptic disorder), and (3) the use of drugs with psychotropic (side) effects or effects on the cardiovascular measures.

## Overview of the Experiment

Preceding the experiment, participants were trained for 4 hours. During the training session the participants were familiarised with the experimental tasks in order to reduce learning effects. The experiment consisted of a sustained

Table 1

Schema of the Experimental Session. See Method Section for Extended Explanation of the Questionnaire Abbreviations and an Overview of the Experiment

	<i>Task characteristics</i>		<i>Measured variables</i>
Preparation 60 minutes	Electrode positioning		
Pre-measurement 20 minutes	GACL, GVKL		
	Memory search task	5 min	Reaction times, accuracy
	Rest measurement	5 min	Heart rate, blood pressure
	Priming and recognition task	5 min	
	Selective attention task	4 min	
	RSME, SEB		
Simulator task 50 minutes	Sidewind		Lateral position on the road (course)
	Dot counting		
	Peripheral stimuli		Reaction times, accuracy
	RSME		Heart rate
Post-measurement 20 minutes	Selective attention task	4 min	Reaction times, accuracy
	Rest measurement	5 min	Heart rate, blood pressure
	Priming and recognition task	5 min	
	Memory search task	5 min	
	RSME, SEB, GACL, GVKL		

divided attention task of 50 minutes duration in a driving simulator, referred to as the "simulator task". This task was administered on two separate days at respectively 50% (condition 1) and 80% (condition 2) of the participants' individual maximum performance level as established during the training session. The order of the two conditions was balanced over the participants. The simulator task was preceded by pre-test tasks and followed by post-test tasks each of 20 minutes duration (for a detailed description of these tasks see Veldman et al., in press). The pre-test tasks were the same tasks as the post-test tasks, only they were administered in reverse order. Following our hypothesis, only physiological results of these tasks are presented in this paper. During the experiment sessions continuous HR was recorded. During the pre- and post-test tasks beat-to-beat finger blood pressure was also recorded. Subjective indicators of mental effort and distress were assessed by self-report questionnaires before and after the pre- and post-test tasks and the simulator task. See Table 1 for a summary.

## Simulator task

The task was based on a paradigm developed by Van Wolfelaar (1991) to study the effects of ageing on divided attention in driving (see Fig. 1). The basic task is lane-tracking on a straight road which is projected on a 20 inch video-monitor. Participants were instructed to drive as straight as possible in the middle of the right lane. Compensatory steering with a regular steering wheel is required to counteract course deviations which are produced by an unpredictable low frequency noise signal. The participants were told that the deviations were due to side-wind. Divided attention is required because two other tasks must be performed simultaneously. The additional tasks involved dot counting and peripheral detection.

The dot-counting task consists of a machine-paced visual analysis task. It required a rapid reaction with the preferred hand to a telephone key pad next to the steering wheel to indicate the number of dots (between 5 and 9). The dots were projected in a small rectangle (visual angle of  $3 \times 2$  degrees) on the road display, slightly below the horizon. Because the dots were presented in the area on which the subject normally focusses when driving straight ahead, no eye movements were required during this task.

The central monitor for the lane-tracking and dot-counting tasks was flanked by two 14-inch monitors on which traffic signs were presented. Participants were required to detect specific traffic signs occurring infrequently at variable intervals (mean 60 seconds, SD = 10 seconds). The traffic signs were represented by arrows, which remained on the screen for 10 seconds, so no time pressure was involved. Participants were instructed to press the claxon on the left or right side of the steering wheel in accordance with the direction the arrow



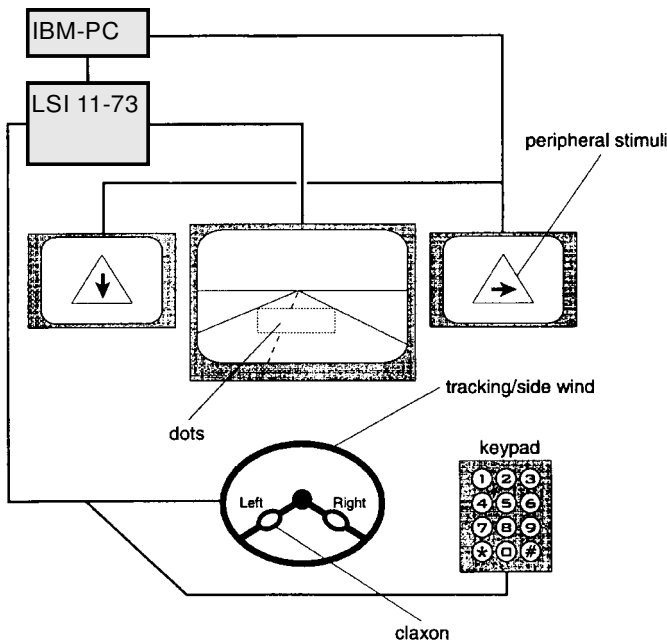


FIG. 1. Symbolic representation of the driving simulator. The participants simultaneously performed three tasks: Tracking, dot-counting, and detecting infrequent peripheral stimuli (after Van Zomeren & Brouwer, 1994).

was pointing. Arrows pointing up or down were to be ignored. This low-even-rate peripheral detection task, was applied because the focus of attention, in this case operationally defined as the functional field of view, was expected to narrow with increasing time on task.

Before the experimental conditions were run, single task difficulty of lane-tracking and dot counting was established individually using an adaptive task procedure during the training session. Adaptation to the lane-tracking consisted of stepwise adjustment (28 consecutive periods of 15 seconds) a multiplication factor which determined the strength of the side-wind. If performance improved, the side-wind was increased, if it deteriorated, the side-wind was decreased. This procedure was maintained until a stable level of steering quality was achieved, meaning that each participant stayed within the boundaries of the right lane for 90% of the time. The individual side-wind score is the average of the side-wind scores of the last three minutes (12 blocks of 15 seconds). As a result of this individual tuning, lane-tracking was assumed to be equally difficult for each participant. The multiplication factor in the divided

attention condition during the experimental sessions was either 50% or 80% of an individual's side-wind score. The individual side-wind score is used as a measure of visual-motor speed. From previous research with this task it is known to be very sensitive to the effects of CHI (Brouwer, Ponds, Van Wolffelaar & Van Zomeren, 1989; Schmidt, Brouwer, Vanier & Kemp, 1996; Veltman, Brouwer, Van Zomeren & Van Wolffelaar, 1996).

The task difficulty of the dot-counting task was established by instructing each participant to carry out the task as fast and as accurately as possible. A new configuration was presented 1 second after a response had been given to the previous one. Therefore, the inter-stimulus interval (ISI) between two dot configurations varied between participants. The ISI that was used in the experimental conditions was either twice (50% load condition) or 1.25% (80% load condition) times the average ISI, obtained in the single task training session.

## Cardiovascular Assessment

An ECG was recorded with disposable, pre-gelled, pre-cordial Ag/AgCl electrodes. Blood pressure was registered using the FIN.A.PRES instrument (MFI-TNO, model 5, Settels & Wesseling, 1985; Wesseling, De Wit, Settels, Klaver, & Arntzenius, 1982). This device allows for non-invasive and continuous registration of finger blood pressure on a beat-to-beat basis, by means of a small cuff wrapped around the finger, which works according to the principle of the unloaded vascular wall (Pe az, 1973).

## Dependent Variables

During the simulator task, lateral position on the road was measured continuously. This was transformed into average scores of the standard deviation of lateral position (SDLP) in consecutive periods of 5 minutes (see also Brouwer et al., 1989; Van Wolffelaar, Van Zomeren, Brouwer & Rothengatter, 1988). Accuracy scores and reaction times were recorded continuously during the dot-counting task and the peripheral detection task. These scores were also transformed into average scores for each consecutive period of 5 minutes.

The Rating Scale for Mental Effort (RSME) was used to assess the participants' perceived level of mental effort (Zijlstra & Van Doorn, 1985). Heart rate was recorded continuously during the simulator task and during the pre- and post-test tasks. Mean HR and HRV were computed for each consecutive period of 5 minutes. By means of spectral analysis, HRV was decomposed into three different bands: a low frequency band ranging from 0.02–0.06 Hz, a mid-frequency band ranging from 0.07–0.14 Hz, and a high frequency band ranging from 0.15–0.50 Hz. The difference in power in the mid-frequency band between the resting condition and the task condition served as an index of

task-related mental effort. This index of task-related mental effort was compensated for both pre- and post-test tasks. Power values of HRV were derived by computing the natural logarithm of the normalised power (squared modulation index, see Mulder, 1988) in the frequency band involved. The cardiovascular data analysis was performed with a Cardiovascular spectral analyses program (CARSPAN; Mulder, 1988; Mulder, Van Dellen, Van Der Meulen & Opheikens, 1988).

Ratings of subjective distress were based on the Subjectief Ervaren Belasting (SEB), the Groningen Adjective Checklist (GACL), and the Groninger Visuele Klachten Lijst (GVKL). The SEB is a rating scale for experienced mental load (Meijman, 1989). The GACL is a mood scale consisting of two subscales related to feelings of activation and to feelings or irritation (Thayer, 1978; translated in Dutch by Hellinga, 1985). The GVKL pertains to the complaints that may occur while working at a computer screen (Koorn et al., 1995). The list consists of six sub-scales related to headache, eye strain, vision, and hand strain, neck and back strain, and leg and foot strain. Physiological distress was indicated by an increase in blood pressure from pre- to post-task. The systolic and diastolic blood pressure were continuously recorded during the pre- and post-test tasks.

In order to explore the process of blood pressure regulation, baroreflex sensitivity (BRS) was estimated from fluctuations in systolic blood pressure and heart rate. BRS was operationalised as the ratio between the changes in inter-beat-interval (IBI in milliseconds) and changes in systolic blood pressure (in mmHg) in the mid-frequency band (Robbe et al., 1987; Wesseling & Settels, 1993; Van Roon, 1998; Veldman et al., in press).

## Statistical Design

All data were checked with regard to frequency distribution and found to be normally distributed. The effects of the performance measures, the mental effort variables, both subjective and physiological, and the subjective distress effects were tested in an ANOVA repeated measurements  $2 \times 2 \times 2$  design. To account for possible initial group differences on the physiological measures in the pre-task, distress effects were tested in an ANCOVA repeated measurements  $2 \times 2 \times 2$  design. In the ANCOVA the mean values obtained at pre-measurement in both the 50% and 80% condition were used as a covariate. In both the ANOVA and the ANCOVA design the between factor was group (CHI group versus control group) and the within factors were conditions (50% or 80% condition), time (pre- versus post-measurement), and rest-task differences. Due to computer failure the performance data on the dot-counting task of two participants were lost. Therefore the degrees of freedom of the reported effects are different in this task. In view of the exploratory character and the small sample size of this study significance levels of  $P < .10$  are reported.

## RESULTS

### Maximum Level of Performance

In the training session the initial individual mean side-wind scores differed significantly between the groups in the single task condition [ $F(1, 14) = 20.1, P < .001$ ]. The mean side-wind score in the control group was 6.2 (SD 2.1) units and 2.3 (SD 1.2) units in the CHI group. The ISI between two dot configurations did not differ significantly between the groups, although the CHI group was slower on average; the mean reaction time in the control group was 2204 (SD 344) ms, and in the CHI group 2468 (SD 412) ms.

### Sustained Performance

During the simulator task, participants had to perform three single tasks simultaneously at an individually adapted level: lane tracking, dot counting, and peripheral detection. No performance differences were found between the two groups on the three tasks, except for missed responses on the dot-counting task; where the CHI group missed slightly more responses than the control group [ $F(1, 12) = 4.2, P < .06$ ]. In the course of the lane tracking task, both groups showed the same time-on-task effect; the standard deviation of the lateral position (SDLP) increased significantly [ $F(1, 14) = 6.3, P < .02$ ]. There was also a significant difference between the two different conditions on SDLP indicating an effect of task-load [ $F(1, 14) = 189.4, P < .001$ ]. Also in the 80% condition both groups showed a much larger increase of the SDLP than at the 50% condition [condition  $\times$  time on task  $F(1, 14) = 9.9, P = .007$ ].

On the dot-counting task the percentage of correct answers was lower in the 80% condition for both groups [ $F(1, 12) = 40.6, P < .001$ ]. Both groups responded faster in the 50% condition [ $F(1, 12) = 34.9, P < .001$ ]. The incorrect answers were errors or missed responses. Both errors and missed responses were higher in the 80% condition [ $F(1, 12) = 11.5, P < .005$ ], and [ $F(1, 12) = 77.7, P < .001$ ] respectively.

On the peripheral detection task both groups missed more peripheral stimuli at the 80% condition [ $F(1, 14) = 4.8, P < .05$ ].

### Mental Effort

No differences were found between the groups in mental effort, neither on the subjective measure (RSME) nor on the physiological measure based on HRV in the 0.07–0.14 Hz band. In the course of the day the level of subjective mental effort increased [ $F(1, 14) = 31.4, P < .001$ ]. HRV decreased between rest and task measurements both in the pre- and post-test tasks [ $F(1, 14) = 3.3, P < .09$ ].

## Distress

Measurements on the three questionnaires for assessing experienced distress revealed group differences on the SEB and GVKL. A heavier task load was reported by the CHI group [SEB;  $F(1, 14) = 3.5, P = .08$ ]. The CHI group reported more visual complaints in the course of the session and the control group less [GVKL  $F(1, 14) = 5.3, P < .04$ ]. However, a similar mood change was found in both the CHI and the control group. Both groups felt less activated at the end of the session [GACL-activation scale  $F(1, 13) = 9.0, P < .01$ ]. No effects were found on the GACL irritation scale.

After correction for possible initial group differences on physiological distress measures in the pre-task no group differences were found on heart rate and baroreflex sensitivity. Figure 2 shows the effects on systolic blood pressure and Figure 3 the effects on baroreflex sensitivity. Systolic blood pressure patterns of the CHI group and the control group were different: The systolic blood pressure of the CHI group increased from pre- to post-test-tasks, the systolic blood pressure of the control group showed a decrease [ $F(1, 13) = 4.1, P < .07$ ]. The diastolic blood pressure followed this same pattern, but these effects were not significant. In the course of the day no further significant effects were found on the physiological distress measures.

## DISCUSSION

The coping hypothesis states that symptoms of mental fatigue in persons who have suffered a severe CHI are induced by a combination of impaired mental

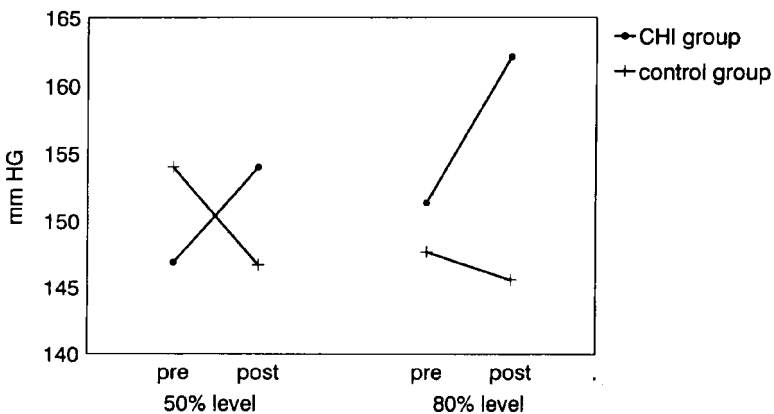


FIG. 2. Mean values of systolic blood pressure in the periods before ('pre') and after ('post') the 50% and 80% task load conditions, given separately for the CHI and the control group.

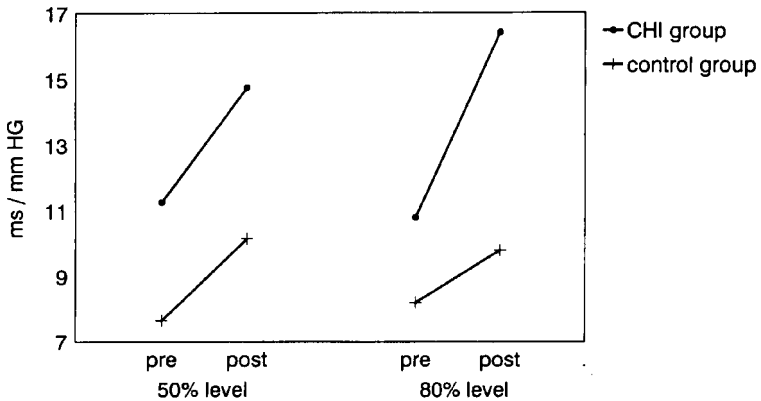


FIG. 3. Mean values of the baroreflex sensitivity in the periods (before ('pre') and after ('post') the 50% and 80% task load conditions, given separately for the CHI and the control group.

abilities and inability to sustain effort to meet the demands of work. Two types of mental abilities are distinguished, viz. cognitive abilities, in particular cognitive speed, and psychophysiological ones, in particular mental fatigue and coping with stress. It was investigated whether severe CHI patients are more than normally fatigued by sustained mental work, operationally defined as sustained performance in a continuous simulator task at 50% or 80% of the participants' maximum capacity. Three types of dependent variables were distinguished: performance measures, measures of mental effort, and measures of distress following sustained mental effort. Mental effort and distress were both defined in terms of self-reports and of cardiovascular variables.

After experimental control for individual differences in single task performance, sustained task performance of the CHI patients was found to be as good as in the control group, both at 50% and 80% of maximal performance. This is consistent with the majority of earlier findings with regard to time-on-task effects on performance. No differences between the groups were found in the measures of mental effort. A different picture emerged from the analysis of the indicators of distress. The CHI group reported higher levels of task load and more visual complaints than the control group, particularly in the 80% load condition. Compared to the control group the cardiovascular indices showed a different profile in the CHI group with regard to the physiological state and short-term blood pressure regulation.

Accepting the results as they stand, two explanations are considered. First, it might be the case that the cardiovascular regulation process as such is impaired. This does not appear likely because the baroreflex response, as an indicator of this regulation process, was found to be sensitive and reactive in the CHI group.

More specifically, no significant differences were found in baroreflex sensitivity between the CHI and the control group. Also, it does not directly explain the group differences in terms of subjective distress. A second possible explanation is in terms of a difference of psychophysiological state between the groups, with the CHI group being inclined more towards a state of distress. To keep the blood pressure constant during a sustained attention task, the BRS increased in both groups during the session. Even though short-term blood pressure regulation in the CHI group was activated, a decrease of the elevated systolic blood pressure level was not attained. A prolonged period of elevated blood pressure is a sign of a state of distress (Veldman, 1992). Together with the reported higher levels of task load, this evidence supports the idea that in the CHI group higher psychophysiological costs are required for sustained task performance.

Provided the initial difficulty level of the simulated work task has been equated in a satisfactory manner, the findings tentatively support the second version of the coping hypothesis described in the introduction. Symptoms of mental overload and distress are reported even though the cognitive demands were reduced to accommodate impaired cognitive capacities. It may be questioned whether establishing equal difficulty of tasks performed separately, establishes also equal difficulty when they are performed concurrently as dual-task performance might be disproportionately impaired after CHI. Previous studies with the dual-task paradigm similar to the one in the present experiment have yielded no evidence for impaired dual-task performance after CHI after experimental control for individual differences in single task performance (Brouwer et al., 1989; Veltman et al., 1996). Still, it might be conjectured that the CHI group reaches the normal divided attention performance with a mental control strategy and a pattern of brain activation which is different from healthy controls. Answering these questions awaits further research.

Methods described here, in which performance and psychophysiological and subjective measurements are combined, could play an important role in identifying mental fatigue and related complaints which are often reported by patients following CHI, but which are difficult to demonstrate with regular neuropsychological tests. Tentative as they are, the results described in the present paper could partly give an indication why CHI patients are more susceptible to mental fatigue and (work) stress. Hopefully, these insights will contribute to a better understanding of the problems that CHI patients experience daily.

## REFERENCES

- Aasman, J., Mulder, G. & Mulder, L. (1987). Operator effort and the measurement of heart rate variability. *Human Factors*, 29, 161–170.

- Aasman, J., Wijers, A.A., Mulder, G. & Mulder, L.J.M. (1988). Measuring mental fatigue in normal daily working routines. In P.A. Hancock & N. Meshkati (Eds.) *Human mental workload*. North Holland: Elsevier Science Publishers BV.
- Brooks, N., McKinlay, W., Symington, C., Beattie, A., & Campsie, L. (1987). Return to work within the first seven years of severe head injury. *Brain Injury*, 1, 5–19.
- Brouwer, W.H. (1985). *Limitations of attention after closed head injury*. PhD. dissertation, University of Groningen, The Netherlands.
- Brouwer, W.H., Ponds, R.W.H.M., Van Wolfelaar, P.C., & Van Zomeren, A.H. (1989). Divided attention 5 to 10 years after severe closed head injury. *Cortex*, 25 219–230.
- Brouwer, W., Riese, H., Hoedemaeker, M., Mulder, B., Veldman, H., Withaar, F., & Cremer, R. (1996). Sustained mental workload in chronic patients with very severe concussions: A psychophysiological study of mental fatiguability. *Brain and Cognition*, 30, 380–383.
- Brouwer, W.H., & Van Wolfelaar, P.C. (1985). Sustained attention and effort after closed head injury: Detection and 0.10 Hz heart rate variability in a low event rate vigilance task. *Cortex* 21, 111–119.
- Crépeau, F., & Scherzer, P. (1993). Predictors and indicators of work status after traumatic brain injury: A meta-analysis. *Neuropsychological Rehabilitation*, 3, 5–35.
- Hellinga, P. (1985). Constructie van de Groninger Adjectief Checklist, GACL. Dept. Arbeids- & Organisatiepsychologie, *Heymans Bulletin HB-85-771-EX*, Psychologische Instituten, University of Groningen, The Netherlands.
- Koorn, R., Veldman, J.B.P., Molenaar, I.W., & Mulder, L.J.M. (1995). Werken aan beeldschermen. De ontwikkeling van een visuele klachtenlijst met behulp van een Mokkenanalyse. [Work on Visual display units: The development of a visual complaints questionnaire using Mokken scale analysis]. *Gedrag en Organisatie*, 8, 318–331.
- Luria, A.R. (1963). *Restoration of function after Brain injury*. Oxford: Pergamon.
- Luteijn, F., & Van Der Ploeg, F.A.E. (1983). *Handleiding Groninger Intelligentie Test (GIT)*. Lisse: Swets & Zeitlinger.
- Manly, T., & Robertson, I.H. (1977). Sustained attention and the frontal lobes. In P. Rabbitt (Ed.), *Methodology of frontal and executive function*, (pp. 135–153). Hove: Psychology Press.
- McKinlay, W.W., Brooks, D.N., Bond, M.R., Martinage, D.P., & Marshall, M.M. (1983). Post-concussional symptoms, financial compensation and outcome of severe blunt head injury. *Journal of Neurology, Neurosurgery and Psychiatry*, 6, 1084–1097.
- Meijman, T.F. (1989). *Mentale belasting en werkstress, een arbeidspsychologische benadering*. Assen/ Maastricht, The Netherlands: Van Gorcum.
- Minderhoud, J.M. & Van Zomeren, A.H. (1984). *Traumatische hersenletsels*. Utrecht, The Netherlands: Scheltema & Holkema.
- Mulder, G. (1986). The concept and measurement of mental effort. In G.R.J., Hockey, A.W.K. Gaillard, M.G.H. Coles, (Eds.), *Energetics and human information processing*. Dordrecht, The Netherlands: M. Nijhoff.
- Mulder, L.J.M. (1988). *Assessment of cardiovascular reactivity by means of spectral analysis*. PhD. dissertation. University of Groningen, The Netherlands.
- Mulder, G., & Mulder, L.J.M. (1981). Information processing and cardiovascular control. *Psychophysiology* 14, 392–402.
- Mulder, L.J.M., Van Dellen, H.J., Van Der Meulen, P. & Opheikens, B. (1988). CARSPAN: A spectral analysis program for cardiovascular time series. In F.J. Maarse, L.J.M. Mulder, W. Slouw, & A. Akkerman (Eds.), *Computers in psychology: Methods, instrumentation and psychodiagnostics*, (pp. 30–38). Lisse, The Netherlands: Swets & Zeitlinger.
- Mulder, B., Veldman, H., Van Der Veen, F., Van Roon, A., Rüdél, H., Schächinger, H., & Mulder, G. (1992). On the effect of mental task performance on heart rate, blood pressure and its vari-



- ability measures. In M. Di Rienzo, G. Mancina, G. Parati, A. Pedotti, A.M. Zanchetti, (Eds.), *Blood pressure and heart rate variability* (pp. 153–166). Amsterdam: IOS Press.
- Oddy, M. (1984). Head injury and social adjustment. In N. Brooks (Ed.), *Closed head injury: Psychological, social, and family consequences*, (pp 108–122). Oxford: Oxford University Press.
- Oddy, M., Humphrey, M., & Uttley, D. (1978). Subjective impairment and social recovery after closed head injury. *Journal of Neurology, Neurosurgery and Psychiatry*, *41*, 611–616.
- Pe az, J. (1973). Photo-electric measurement of blood pressure, volume and flow in the finger. In R. Albert, W. Vogt, & W. Helbig (Eds.), *Digest of the 10th international conference on medical and biological engineering* (p. 104). Dresden: Conference Committee.
- Ponsford, J.L., & Kinsella, G. (1989). *An investigation of attentional deficits following closed head injury*. Paper presented at the first biannual congress of the International Association for the Study of Traumatic Brain Injury, San Jose, California, USA.
- Richardson, J.T.E. (1990). *Clinical and neuropsychological aspects of closed head injury*. London: Taylor & Francis.
- Robbe, H.W.J., Mulder, L.J.M., Rüdell, H., Veldman, J.B.P., Langewitz, W.A., & Mulder, G. (1987). Assessment of baroreflex sensitivity by means of spectral analysis. *Hypertension*, *10*, 538–543.
- Robertson, I.H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). ‘Oops!’: Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, *35*, 747–758.
- Russell, W.R. (1971). *The traumatic amnesias*. New York: Oxford University Press.
- Schmidt, I.W., Brouwer, W.H., Vanier, M., & Kemp, F. (1996). The flexible adaptation to changing task demands in severe closed head injury patients: A driving simulator study. *Applied Neuropsychology*, *3/4*, 155–165.
- Settels, J.J., & Wesseling, K.H., (1985). FIN.A.PRES: Non-invasive finger arterial pressure waveform registration. In J.F. Orlebeke, G. Mulder & L.P.J. Van Doornen (Eds.), *The psychophysiology of cardiovascular control*, (pp. 267–283). New York: Plenum Press.
- Snijders, J.Th., & Verhage, F. (1958). *Opstelling van een intelligentietest voor volwassenen met speciale aandacht voor bejaarden*. Groningen, The Netherlands: Psychologisch Instituut Heymans, University of Groningen.
- Thayer, R.E. (1978). Factor analysis and reliability studies on the Activation-Deactivation Adjective Check List. *Psychological Report*, *42*, 747–756.
- Van Roon, A.M. (1998). *Short term cardiovascular effects of mental tasks. Physiology, experiments and computer simulation*. PhD. dissertation. University of Groningen, The Netherlands.
- Van Wolfelaar, P.C. (1991). A tracking task disguised as a driving simulator. In L.J.M. Mulder, F.J. Maarse, W.P.B. Sjouw, & A.E. Akkerman, (Eds.), *Computers in psychology; applications in education, research and psychodiagnosics*. Lisse: Swets & Zeitlinger.
- Van Wolfelaar, P.C., Van Zomeren, A.H., Brouwer, W.H., & Rothengatter, J.A. (1988). Assessment of fitness to drive of brain damaged persons. In J.A. Rothengatter, & R. De Bruin (Eds.) *Road user behavior, theory and research*, (pp. 302–309). Assen: Van Gorcum.
- Van Zomeren, A.H., & Brouwer, W.H. (1994). *The clinical neuropsychology of attention*. New York: Oxford Press.
- Van Zomeren, A.H., & Brouwer, W.H., & Deelman, B.G. (1984). Attentional deficits: the riddles of selectivity, speed and alertness. In: Brooks, N. (Ed.), *Closed head injury: Social and family consequences* (pp. 74–107). Oxford: Oxford University Press.
- Van Zomeren, A.H., & Van De Burg, W. (1985). Residual complaints of patients two years after severe head injury. *Journal of Neurology, Neurosurgery and Psychiatry*, *48*, 21–28.
- Veldman, J.B.P. (1992) *Hidden effects of noise as revealed by cardiovascular analysis*. PhD. dissertation, University of Groningen, The Netherlands.

- Veldman, J.B.P., Mulder, L.J.M., Van Roon, A.M., Van Der Veen, F.M., & Mulder, G. (in press). Test measurements are a powerful tool in determining cardiovascular effects of long lasting mental work. *Journal of Psychophysiology*.
- Veltman, J.C., Brouwer, W.H., Van Wolfelaar, P.C. & Van Zomeren, A.H. (1996). Central executive aspects of attention in subacute severe and very severe closed head injury patients: Planning, inhibition, flexibility and divided attention. *Neuropsychology* 10, 357–367.
- Wesseling, K.H., & Settels, J.J., (1993). Circulatory model of baro- and cardio-pulmonary reflexes. In M. Di Rienzo, G. Mancia, G. Parati, A. Pedotti, A. Zanchetti, (Eds.), *Blood pressure and heart rate variability* (pp. 56–57). Amsterdam: IOS Press.
- Wesseling, K.H., De Wit, B., Settels, J.J., Klaver, W.H., & Arntzenius, A.C. (1982). On the indirect registration of finger blood pressure after Pe az. *Functional Biological Medicine*, 1, 245–250.
- Whyte, J., Polansky, A., Fleming, M., Branch Coslett, H., & Cavallucci, C. (1995). Sustained arousal and attention after traumatic brain injury. *Neuropsychologia*, 33, 797–813.
- Zijlstra, F.R.H., & Van Doorn, L. (1985). *The construction of a subjective effort scale*. Report: Delft University of Technology, The Netherlands.

Manuscript received August 1997

Revised manuscript received November 1998