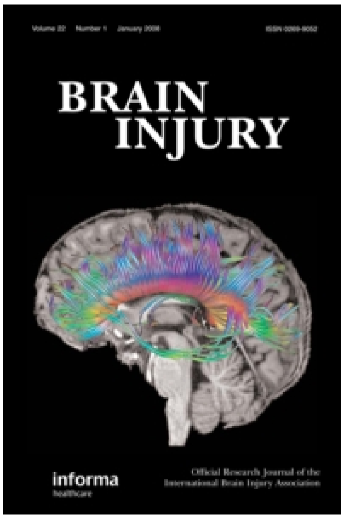

Brain Injury
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713394000

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Online Publication Date: 01 March 2005

To cite this Article Pietrapiana, Paolo, Tamietto, Marco, Torrini, Gaia, Mezzanato, Tiziana, Rago, Roberto and Perino, Claudio(2005)'Role of premorbid factors in predicting safe return to driving after severe TBI',Brain Injury,19:3,197 — 211

To link to this Article: DOI: 10.1080/02699050400017197

URL: http://dx.doi.org/10.1080/02699050400017197

Brain Injury, March 2005; 19(3): 197–211

Taylor & Francis
Taylor & Francis Group

ORIGINAL ARTICLE

Role of premorbid factors in predicting safe return to driving after severe TBI

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Abstract

Primary objective: The present study explored the possibility of predicting post-injury fitness to safe driving in patients with severe traumatic brain injury (TBI) ($n = 66$).

Methods and procedure: Sixteen different measures, derived from four domains (demo/biographic, medico-functional, neuropsychological, and psychosocial) were used as predictor variables, whereas driving outcomes were assessed in terms of driving status (post-TBI drivers versus non-drivers) and driving safety (number of post-TBI car accidents and violations).

Main outcomes and results: About 50% of the patients resumed driving after TBI. Compared to post-TBI non-drivers, post-injury drivers had shorter coma duration. With regard to driving safety, the final multiple regression model combined four predictors (years post-injury, accidents and violations before TBI, pre-TBI-risky-personality-index, and pre-TBI-risky-driving-style-index) and explained 72.5% of variance in the outcome measure.

Conclusions: Since the best three predictors of post-injury driving safety addressed patients' premorbid factors, the results suggest that in order to evaluate the actual possibility of safe driving after TBI, it would be advisable to consider carefully patients' pre-TBI histories.

Keywords: *TBI, brain injury, driving safety, premorbid factors*

Introduction

For subjects recovering from traumatic brain injury (TBI), the return to driving represents an extremely important aspect in resuming a normal lifestyle, but it also constitutes a problem of safety and public health, considering the great number of people directly or indirectly involved. Although about 50% of survivors of TBI resumed driving, nearly two thirds of them did so without specific medico-legal examination or formal evaluation [1–8]. Lacking a standard method for the assessment of driving capabilities, specialists have developed their own procedures. These differ in many aspects, but generally include a pre-driving examination and an on-road evaluation as the criteria for the determination of fitness to drive [9–11]. Yet behind-the-wheel tests are still not part of an established common procedure in many countries, and are not easy for hospitals or rehabilitation centres to organize [12, 13]. Furthermore, they are costly for patients in terms of money, time and energy required [14]. So, in order to assess driving fitness of patients with brain-damage it is vital to develop appropriate and reliable pre-driving predictive measures to discriminate between safe and unsafe drivers and reduce the risk of the latter being allowed to resume driving.

Unfortunately, the results of various studies in predicting driving outcome from different pre-driving parameters are highly inconsistent, and range from a reported predictive power of about 20% to 94% of explained variance (the predictive power refers to the proportion of variance of the outcome measure that can be explained by predictor variables) [5, 9–11, 15–25]. For instance, Galski and colleagues evaluated the predictive power of 21 physical and neuropsychological tests thought to assess visuo-perceptive, motor, and cognitive skills relevant for safe driving, against

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ISSN 0269–9052 print/ISSN 1362–301X online
DOI: 10.1080/02699050400017197

a behind-the-wheel evaluation divided into 26 different tasks [16]. They found a substantial lack of internal and external validity and, neither the overall pre-driving evaluation outcome, nor any of the individual items were significantly correlated with the behind-the-wheel evaluation performance. The best predictor was 'left peripheral vision' ($\phi = 0.34$) followed by 'inattention' ($\phi = 0.29$). Similarly, Fox and co-workers reported a failure to predict on-road driving performance from medical and neurological tests [9].

In contrast with previous findings, Galski et al. combining neuropsychological tests, driving-simulator tasks, and off-road driving outcome, reported a predictive power of 93% evaluated against a behind-the-wheel performance measure [11]. Similar results were also obtained by Gouvier and co-authors [17], who administered a battery of Wechsler Adult Intelligence Scale, and by Korteling [18], who reported a high correlation between performance on a duration-estimation task and a closed-course driving task ($r = 0.94$).

Other studies have purported to account for about 40% to 50% of the variance in the driving outcome measure [19–21]. In Sivak's et al. research [19], which studied the role of perceptive and cognitive skills on driving, the 'picture completion test' yielded the strongest correlation ($r = 0.72$; $r^2 = 0.52$) with a 'composite driving index' derived from an on-road assessment of five different aspects of the patients' performance. Korteling and Kaptein [20] explained the 35.3% of variability in rated driving performance combining two laboratory neuropsychological tests ('perceptual speed' and 'tracking reaction') with coma duration and reported driving experience. Finally, Coleman and colleagues [21] were able to correctly classify 80.3% of the subjects ($r^2 = 0.53$) between drivers and non-drivers using neuropsychological tests, an index of patients' awareness of their own deficits, and two other subjective indexes on perception of the patients' ability to drive safely.

This incompatibility between several authors (and sometimes between different works by the same authors) reflects experimental approaches which differ in at least four main aspects: the type of predictors used, i.e. the independent variables adopted in various researches as pre-driving screening; the type of outcome measures considered as the criterion for the determination of fitness to drive (also called the criterion or dependent variable, or external criterion); the sample of subjects studied; and the length of the follow-up considered.

As predictors, parameters and tests have been taken from four different sources: simulator and off-road closed course (evaluating driving performance on basic car manoeuvring skills, e.g. driving around cones, straight tracking or braking); demographic and biographic variables (age, driving experience before TBI, education and years post-injury); medical data (e.g. Glasgow Coma Scale, coma duration, Disability Rating Scale, etc.); and neuropsychological and behavioural tests assessing cognitive capacities, perceptual-motor skills, and functional abilities.

Even though Galski et al. [11] and Odenheimer et al. [25] reported that the closed course outcome or simulator performance of their subjects accounted for, respectively, 63% and 36% of the variance in the on-road performance, in most cases, closed-course or simulator evaluations yielded little useful information about actual driving behaviour observed on public roads [10, 16, 19, 24]. Similar results have been found for demographic variables that did not show any significant correlation with the open-road outcome [17, 19–21].

Contradictory results have been obtained on the predictive power of medical data. For instance, in some studies, the subjects' rate at the Glasgow Coma Scale (GCS), the Functional Independence Measure (FIM), as well as coma duration or medical evaluation in general, were relevant in previewing driving outcome [7, 20, 26], whilst in others they were not [9, 17, 19, 21].

Finally, neuropsychological tests are generally considered useful tools and have shown some value in the assessment of driving fitness, especially those tests involving focused and divided attention, information processing speed, working memory and perceptual-motor skills [4, 9, 11, 16, 17, 19–21, 23, 27–32]. Yet their specific role is far from clear, reflecting the wide differences among the tests selected and the various driving outcome measures used as the criterion variable.

Most of the research so far reviewed has tended to consider driving a perceptual-motor skill and has consequently adopted tests tapping these abilities [33]. Such aspects are obviously important in assessing the driving fitness of post-TBI subjects, but in order to formulate realistic judgements about their actual ability to drive, it is also necessary to consider other higher-order capacities. The lack of consistency among different research can be partially explained by the low consideration given to these aspects [4, 9, 34]. In fact, driving safely is much more than just mechanically operating a vehicle, and it is never completely routine. Driving requires planning, concentration, inhibition of distractors, foresight, anticipation, problem-solving capacities, the ability to interpret rapidly complex arrays of multimodal stimuli, and prompt, effective, and calm reactions. Some post-TBI subjects display a hidden deficit in one or more of these domains and may have loss of emotional control under certain circumstances [35–44]. Others may also be unaware of deficits and may subjectively feel perfectly able and fit to drive again [45–47]. Conversely, basic deficits and risk of crashes can be moderated by higher-order cognitive abilities such as self-awareness of disease [21, 48–52]. It follows that patients with severe physical or cognitive disabilities, and a high risk factor for accidents, can be at low risk if they appreciate the relevance of their deficits and act consequently. According to this view, several theoretical approaches to modelling driving behaviour (like motivational [53] or cybernetic models [11]) have addressed functional and higher-order cognitive aspects rather than perceptual-motor skills alone (see Ranney [53] for a review).

Michon [54, 55] proposed a conceptual model that schematizes driving into three main hierarchically interconnected components: strategic, tactical and operational. The strategic level deals with decisions connected with driving which may be taken without time constraint (e.g. day and hours for travelling, route to be followed, stops for petrol, food, rest, etc.). At this level, dealing with danger consists in risk acceptance. A safe driver can compensate for lower level impairments by taking good strategic traffic decisions, for example, choosing less crowded roads or avoiding rush hour traffic. The tactical level has to do with driving planning, flexibility and adaptation (e.g. adequate speed and limits, weather, decisions on changing lane, overtaking, slowing down, etc.). These operations have time constraints and, among other abilities, require focused attention, adequate judgement and anticipation, inhibition of distractors, and realistic awareness of self and environment. The operational level mainly concerns the perceptual and mechanical ability to use a motor vehicle and depends on training, visuo-perceptual spatial scanning, motor strength and sequencing, rapidity of primary reaction time, etc.

Recently, some researchers have addressed higher-order cognitive and personality aspects trying to consider together all three levels: operational, tactical, and strategic [5, 11, 16, 20, 21, 50–52, 56]. Brower and Van Zomeren recognized social responsibility as an important additional factor in the assessment of driving fitness [57]. Coleman et al. [21], Rapport et al. [50–52], and Galski and co-authors [16] reported that the risk of car accidents was more accurately predicted by measures of patients' awareness of disease than by measures of physical impairment or low-level perceptive-motor skills. In the study of Galski et al. [11] the driving instructor who rated patients' performance in an open-road examination, also considered critical behaviours such as impulsivity, distractibility, anxiety, or inattention. Apart from considering the direct effects of the injury, literature still critically ignores the relationship of driving outcome to pre-injury driving habits, or psychosocial traits, as well as the influence of significant others' perception of patients' fitness to drive.

To summarize, different predictors have been evaluated in assessing driving outcome after brain injury. The most promising are medical and neuropsychological measures, but uncertainty about their specific role arises from differences in the choice of tests and of adequate outcome measures. Furthermore, these tests have accounted for basic functional and perceptual-motor skills but critically lack the other higher-order cognitive and psychosocial capabilities indispensable for safe driving. Encouraging results come from recent studies that, considering different sources of information from medical to psychological domains, improved the explanatory power of the predictive measures used. Other possible relevant aspects such as pre-injury behaviour and personality traits are not yet adequately considered and validated as predictors of driving fitness.

The second major aspect that differs among research is the type of outcome measures considered as the criterion for determining fitness to drive. Closed-course and off-road evaluations have been criticized, when used as criterion variable, because they do not provide information about a driver's ability in the real world where interactions with other cars and complex traffic patterns are required [11, 16, 19, 24, 57–59]. Apart from the lack of ecological validity, some studies indicate that closed courses have limited correlation with on-road evaluations [11, 16, 19, 24]. The wide majority of research in the field used on-road evaluations as a direct measure of driving abilities (see Fox et al. [10] for a review). This choice is probably related to the fact that on-road assessment is the commonly accepted licensing test for normal persons learning to drive. However, on-road assessment is itself a measure to predict driving outcomes in the real world for long periods that critically depend on several other factors such as environmental conditions, intensity of traffic, general state of the driver, car performance and frequency of use. Surprisingly, a direct relationship between on-road assessment and real world driving performance has been taken for granted. Few studies have attempted to establish the reliability of this relationship by evaluating, for instance, the predictive value of on-road testing against traffic violations or car accidents [21]. There are several theoretical and empirical reasons supporting a sceptical position that criticize the validity of on-road evaluations. From a theoretical point of view, on road-assessments do not elucidate the strategic level of driving skill that includes all the decisions made before actual driving starts [4, 10]. Another difficulty in assuming that on-road tests are valid arises from the consideration that highly-skilled drivers sometimes have above-average accident rates: drivers do not always drive as they did during their licensing test [33, 60, 61]. These arguments undermine the supposed external validity of on-road assessment.

Additional sources of variability arise from the extremely different procedures used in assessing on-road performance that are consequently hardly comparable. In general, little attention has been devoted to reliability or standardization of the on-road assessment [10]. Some studies used a short informal test [9, 11, 20], whereas others adopted a standardised course with predetermined manoeuvres [19, 56, 62, 63]. In Sivak's and colleagues work [19], a 17-km course was standardized for driving manoeuvres, traffic density and difficulty, then driving performance was evaluated on 144 predetermined behaviours. Engum and collaborators [56] rated 144 driving manoeuvres on six basic actions. Korteling and Kaptein [20] judged subjects' driving performance in a moderately formalized test on five dimensions further subdivided into other elementary driving aspects singly rated on a scale ranging from 2 to 9. Fox and co-authors [9] observed five areas of driving performance such as planning and judgement, vehicle positioning, reaction time, speed control and observation.

Equally different are various scoring approaches that alternatively calculated the number of correct manoeuvres, or rated predetermined driving actions on a 5 or 8 point scale [20, 64]. Other authors considered the time taken for various actions [30] or used a pass–fail rating for each manoeuvre [11, 16, 24, 25, 65, 66] or even adopted a qualitative description of driving skills [9, 67, 68]. Many studies used one rater in the car during on-road assessment (a driving instructor or an occupational therapist) [24, 31, 67, 68] whilst others used two or more raters [9, 25, 64, 66]. In addition, most research that adopted the on-road evaluation as an outcome measure has included raters who were not blind to the diagnosis of subjects, thus possibly introducing a systematic bias.

One last criticism of on-road tests relates to the issue of internal validity. Jones [62] administered his highly standardized test to 194 high-school driving students and then re-tested 67 of them 2 weeks later: test–retest correlation was only 0.40. Van Zomeren et al. [69] and Galski et al. [16] found that the overall rating of driving outcome did not relate to single items calculated in terms of driving error score, whilst Brooke et al. [30] reported a higher correlation between global rating and single manoeuvre score ($r = 0.58$).

Recently, some studies used car accidents or traffic violation rates (or both) as a driving outcome measure [7, 21, 26, 70]. This criterion clearly has greater ecological and external validity than on-road evaluations and accounts for the strategic, tactical and operational levels. Yet neither is this choice free from problems. Car crashes are quite rare events and produce a variable with restricted range. Consequently, this parameter could have poor statistical power [10, 53]. Furthermore, accidents may have different causes not necessarily related to unsafe driving or individual factors. Conversely, drivers' errors or unsafe behaviours may not always result in accidents. On the other hand, one could argue that, as these factors are distributed randomly through the population, they should not affect the external validity of the measure.

To summarize, three types of outcome measures have been adopted as criterion variables for determining fitness to driving: off-road tests, on-road assessments and the number of accidents after resuming driving. Off-road tests yielded very limited value in predicting driving behaviours in daily open-road situations. On-road evaluation has been used by most of the researchers assessing driving outcomes. While having greater ecological validity, on-road evaluation does not address reliability and standardization, nor does it deal with strategic level. Moreover, its external and internal validity is not clearly established. Car accident rate seems the most promising outcome measure, at least in terms of ecological and external validity. Nonetheless, since few studies have used this measure, an exhaustive judgement of the pros and cons is not yet available.

The third source of variability among research studies relates to different populations studied. Various researchers examined fitness to drive in persons with Alzheimer's disease [27, 71, 72], in subjects with different types of dementia [25, 66], in patients with brain damage with or without aphasia [63], in TBI subjects [7, 18, 20, 21, 30], in mixed clinical population (typically TBI and cerebrovascular patients together) [11, 16, 28, 29], or in normal subjects [60, 73]. Obviously, findings in one population do not necessarily generalize to another. Furthermore, studies addressing the same population differ with respect to the degree of functional impairment of subjects involved. In fact, patients in Coleman's et al. paper [21] sustained a moderate to severe TBI ranging from 3 to 12 GCS score, whilst the sample tested by Korteling and Kaptein [20] sustained extremely severe TBI with average coma duration of 33 days and high standard deviation ($SD = 51$ days). The involvement of more extreme cases enhances the magnitude of correlations among various measures, but further reduces the possibility to generalize results. Consistently, Korteling and Kaptein [20] found a predictive power of coma duration whereas other authors failed to address severity of injury as a potentially important predictor [9, 17, 19, 21, 23].

Lastly, the fourth aspect that differs among studies is the length of follow-up, which ranges from

3 months to 1 year [22, 23, 30, 74]. The variability of the period taken into consideration could perhaps explain why some authors reported time since injury as an important predictor [21] and other authors did not [17, 19]. In TBI patients, the functional recovery is typically slow and occurs during the whole year after brain injury and sometimes beyond [75–78]. Consequently, results of studies adopting a 3- or 6-month follow-up do not generalize to the majority of TBI patients.

The present study had two aims. The first was to provide data on a sample of Italian TBI-patients and to contrast those subjects who resumed driving with those who did not, with respect to demo/biographic and medical characteristics. The second, and main, aim of the research was to understand to what extent different measures could predict fitness to return to *safe* driving after TBI. To do so, on the basis of the above-mentioned literature, we took into consideration as predictors four kinds of data, with the purpose of dealing with all the three levels entailed in driving properly: operational, tactical and strategic level. Demographic and medico-functional parameters were thought to address operational level, neuropsychological tests and cognitive status measures dealt with tactical level, and psychosocial data on personality traits and pre-TBI habits and behaviours explored strategic level and emotional domain. We expected to find higher-order parameters more predictive of driving safety than lower-order ones and to improve the explanatory power of the predictors by combining them together. As an outcome measure of fitness to safe driving, we used a composite index that considered the number of car accidents and the number of traffic violations that occurred after TBI. In order to reduce other intervening sources of variability, all subjects had sustained severe TBI with GCS score less than or equal to 8, and entered the sample not before 1 year after TBI.

Method

Participants

Sixty-six pairs of adults participated in this research. Each pair consisted of one patient with traumatic brain injury, who had completed his/her rehabilitation program at Ausiliatrice Hospital of Turin, and one close relative or significant other who identified him/herself as the chief caregiver and reported knowing the patient well before TBI. Patients with history of developmental disabilities or psychiatric disorders were excluded from the sample. The 66 patients were 54 males (81.8%) and 12 females (18.2%), who were between the ages of 21 and 62 years when the research was conducted ($M = 34.36$; $SD = 9.41$). Age at the time of injury ranged between 15 and 60 years ($M = 28.74$; $SD = 9.20$) (see also Table I). Time post-injury varied from 1 to 16 years ($M = 5.61$; $SD = 3.73$). All patients in the sample sustained a severe TBI with GCS score ranging from 3 to 8 ($M = 5.89$; $SD = 1.9$) and an average length of coma duration (LOC) of 12.44 days ($SD = 8.19$). Patients were from 18 to 24 years old at driving license achievement ($M = 18.85$; $SD = 1.56$) and reported a mean driving experience before TBI of 10.27 years ($SD = 8.46$). Education had lasted from 5 to 18 years ($M = 10.59$; $SD = 3.24$). To be included in the sample, patients who reported driving again after TBI ($n = 31$; 47%) had to have driven for at least a year, so that the follow-up would be sufficiently long. Two patients were excluded because they had been driving for too short a time. Close relatives or significant others were 25 men (37.8%) and 41 women (62.12%), between 21 and 78 years old ($M = 40.38$; $SD = 13.86$).

Predictors: Medical records

GCS. This 15-point scale is a widely used index of acute trauma severity and evaluates the patient's level of awareness during the first 24 post-injury hours. Three categories of patient's responses are rated: eye opening, best verbal response, and best motor response. The lowest score is 3 indicating no response; the highest score is 15 and indicates that the patient is alert and aware of his/her surroundings. Taken as a predictive index of long-term recovery, a GCS score of 13 or higher relates to a mild brain injury, a score ranging from 9 to 12 corresponds to a moderate injury and a score of 8 or less refers to a severe brain injury [79].

LOC. Length of coma duration is considered one of the indicators for predicting the level of a patient's recovery during the first few weeks and months after injury. In fact, coma duration correlates to both severity of post-traumatic amnesia (PTA) and length of recovery time [80, 81]. Coma lasting seconds to minutes results in PTA of hours to days; recovery plateau occurs over days to weeks. Hours or days of coma result in PTA lasting days to weeks, and some months are required for general recovery. Coma lasting weeks leads to PTA of months; recovery plateau occurs over months to years.

Predictors: Functional status at discharge

Functional Independence Measure and Functional Assessment Measure (FIM-FAM). The FIM and FAM are the most widely used assessment scales of functional disability level [82, 83]. These scales assess

Table I. Demographic, biographic, and medical characteristics of post-TBI drivers versus non-drivers.

Variables	Group: Drivers ($n=31$)	Group: Non-drivers ($n=35$)	Total sample ($n=66$)	$F(1, 64)$	p
Age at interview (years)					
Mean	33.50	35.11	34.36	0.478	0.492
SD	10.30	8.63	9.41		
Age at TBI (years)					
Mean	28.52	28.94	28.74	0.034	0.854
SD	10.77	7.70	9.20		
Education (years)					
Mean	10.6452	10.5429	10.5909	0.016	0.899
SD	3.2511	3.2840	3.2438		
GCS					
Mean	5.8710	5.9143	5.8939	0.008	0.927
SD	1.8392	1.9759	1.8984		
LOC (days)					
Mean	10.5143	14.6129	12.4394	4.323	0.042
SD	6.6570	9.2761	8.1940		
Age at licence achievement					
Mean	18.6452	19.0645	18.8548	1.113*	0.296
SD	1.2530	1.8246	1.5665		
Years of driving before TBI					
Mean	10.25	10.29	10.27	0.000	0.987
SD	9.85	7.16	8.46		
Years post-injury					
Mean	4.98	6.17	5.61	1.692	0.198
SD	2.72	4.40	3.73		
Accidents and violations before TBI					
Mean	1.65	1.77	1.71	0.075	0.785
SD	1.84	1.90	1.85		

*Four subjects sustained TBI before achieving driving licence and never obtained it afterwards. Consequently, *df* on this variable are 1.60.

major functional areas involved in community integration and daily living. Taken together, the measure includes 30 items divided into three main categories: (1) motor items; (2) psychosocial items; (3) cognitive items. Motor items are, in turn, divided into the following sections: Self-care (items 1 to 7); Sphincter control (8, 9); Transfers (10–13); Locomotion (14–16). The psychosocial section consists of four items: Social interaction (item 22: representing how one deals with one's own needs together with the needs of others); Emotional status (23); Adjustment to limitations (item 24: includes denial/awareness, acceptance of limitations and realistic expectations for long-term recovery); Employability (25). Finally, five items deal with cognitive functioning: Problem solving (item 26); Memory (27); Orientation in space and time (28); Attention (29); Safety judgement (item 30 assesses the ability to understand the nature of situations and to identify risks involved). Each item rating ranges from 1 to 7. The scoring is based upon the grade of supervision required by the patient: from total assistance to complete autonomy. The rating scale is divided into three segments: complete dependence (1,2), modified dependence (3–5) and no dependence (6,7).

The scale was administered at discharge. We excluded from the analysis items treating communication abilities (items 17–21) because they were outside the actual aims of the present study, as well as the first nine motor items which addressed functions considered too easy for the patients' status at discharge.

Predictors: Neuropsychological measures

Visual Search Test (VST). This is a paper-and-pencil test and consists of a series of three trials of visual cancellation tasks. In the first trial the respondent identifies and marks through all occurrences of a target digit among many other different digits. The second and third trials are similar except for the number of target digits (two and three, respectively) to be contemporarily marked among distractors. The task should be completed as quickly as possible. Scoring consists of the number of digits crossed out within 45 seconds per trial. The VST yields an overall attention score since the task requires focused, divided and sustained attention. Furthermore, the test points out the presence of visual field defects or attentional deficits such as unilateral spatial neglect which can affect the perception of portions of the visual space. The present study used the Italian version of the test with the age and education-corrected scaled score [84].

Wechsler Adult Intelligence Scale-Revised, Symbol-Digit Subtest (WAIS-R SDS). This paper-and-pencil test is one of the WAIS-R performance subtests, and it was taken from the Italian version of the scale [85]. The patient is provided with a decoding key with nine symbols, each one corresponding to a specific number from 1 to 9. A long list of symbols is then presented. The subject is asked to match each symbol with the corresponding digit. The scoring consists of the number of digits correctly replaced within 90 seconds. Scores were calculated according to the Italian version of the test with the age-corrected scaled score. The SDS evaluates non-verbal executive functions such as speed of execution in a complex task involving cognitive abilities, e.g. perceptual organization, information processing, praxical abilities and working memory.

Predictors: Self report measures

Pre-TBI-risky-personality index. We made up this rating scale in order to point out the possible presence of a risky lifestyle in the time before TBI, with particular consideration for behaviours and attitudes connected with personality structures of the impulsive cluster (cluster B of DSM IV [86]). For this purpose, close relatives or significant others were interviewed with a semi-structured questionnaire and asked to rate each one of the following seven behavioural traits on a 4-modality Likert scale: *Indolence, impulsiveness, calmness, irritability, sociability, aggressiveness, and tendency to inattention.* The final score represented a global pre-TBI-risky-personality index and ranged from a minimum of 7 to a maximum of 28, and was calculated by adding the score on each of the seven items (before calculating the final score, the polarity of rating scales associated with *calmness* and *sociability* had been reversed). High scores indicated that the subject matched closely personality traits associated with the impulsive cluster, and thus had a high level of risky behaviours before TBI.

Pre-TBI-risky-driving-style index. Close relatives or significant others evaluated the patient's degree of respect for traffic regulations before TBI. They rated each of the following five critical aspects involved in patient's driving behaviour on a battery of 4-modality Likert scales: *caution, tendency to inattention, competitiveness, observance of the road traffic rules, and reckless behaviour*. The global score, indicating a pre-TBI-risky-driving-style index, was calculated just as for the afore-described pre-TBI-risky-personality index and ranged from 5 to 20. Again, higher scores were associated with a riskier driving style.

Driving records. Complete driving records were collected by interviewing close relatives or significant others by means of the same semi-structured questionnaire used for rating pre-TBI personality and driving style. We took into consideration: age at licence achievement, years of driving before TBI, medical consensus for return to driving, all disciplinary measures taken towards the driver, and possible car crashes which happened before and after TBI. A composite score, created by summing the number of occurring car accidents and traffic rules violations after TBI, was taken as an objective outcome measure of the patient's fitness to drive safely again. In fact, we assumed that being involved in one or more car accidents or traffic violations, even of minimal extent and without consequences, is still evidence of cognitive and behavioural deficits such as inattention and impulsivity which, after all, can compromise driving safety. Moreover, the composite score represents a variable with a larger range than car accidents alone, and increases the statistical power of the measure.

Procedure

Except for self-reported measures (e.g. pre-TBI-risky-personality index; pre-TBI-risky-driving-style, and subject's driving history) recorded in a telephonic semi-structured interview to close relatives or significant others, the remaining data was collected retrospectively from clinical records: some in acute phase (medical records) and some at discharge from our Rehabilitation Centre (FIM-FAM scores and neuropsychological tests). All data regarding medico-functional and neuropsychological characteristics had been acquired long before the aims of this research were formulated. All subjects gave informed consent and received no compensation for participating in the study.

Presentation of data analysis results will be organized as follows. Firstly, post-TBI drivers and non-driver patients will be assessed with regard to their demographic, biographical and medical characteristics using a series of univariate analysis of variance (ANOVA) and chi-square tests. Secondly, all different types of predictors will be singly evaluated against the outcome measure collected on those patients who resumed driving after TBI with a series of simple correlations (Pearson r). Finally, predictive power of different kind of measures, taken together, will be assessed by means of multiple regression analysis, where the dependent variable was the described outcome measure of fitness to safe drive.

Results

Among the 66 patients entered in the sample, 31 (47%) resumed driving again after TBI, whereas 35 (53%) did not. Men and women were equally distributed between drivers and non-drivers, as indicated by a chi-square test, χ^2 $(1) = 0.76$, $p = 0.38$. Other demographic, biographic (driving history) and medical variables potentially associated with resumption of driving were examined. Mean and standard deviation of all of these variables split up for post-TBI driver and non-drivers, and the results of univariate ANOVAs, are reported in Table I.

The results indicated that drivers and non-drivers did not significantly differ on demographic and biographic driving-related variables such as age, age at TBI, years post-injury, education, age at license achievement, years of driving before TBI, or number of car accidents and violations before TBI ($p > 0.05$ for all variables). Between medical variables, only LOC differed significantly between groups ($p = 0.042$; $\eta^2 = 0.063$), whilst GCS score recorded in acute phase did not. The discriminating value of LOC seems to indicate that severity of injury was the only determinant of whether patients resumed driving after TBI. The lack of significance for GCS, the other medical data related to injury severity, might be attributed to the homogeneity of our sample on this measure (all patients had GCS ranging from 3 to 8). This homogeneity produced a variable with a restricted range and did not allow possible differences between drivers and non-drivers to be found.

Predictive power of individual measures

Descriptive statistics of all predictors and the outcome measure collected on those patients who resumed driving after TBI are listed in Table II.

Eleven subjects (35.5%) were subsequently involved in one or more car accidents, while the remaining 20 (64.5%) had no car crashes after their return to driving. Twenty-one patients (67.7%) began to drive again under medical control and ten (32.3%) did so without undergoing any specific examination. Table III shows simple correlations (Pearson *r*) among FIM-FAM ratings on different items of the same categories (motor, cognitive and psychosocial items).

All FIM-FAM items were strongly correlated and highly statistically significant, indicating that either each dimension of a given category was strictly interconnected, or that even professional raters were not able to judge them separately. In any case, it was not meaningful to consider all items separately in the following analysis. For this reason we constructed an overall FIM-FAM index for each of the three categories by averaging different ratings for every subject. In order, means for overall motor, cognitive, and psychosocial FIM-FAM scores were 6.47 ($SD = 0.47$), 6.25 ($SD = 0.58$), and 6.02 ($SD = 0.59$).

To evaluate the predictive power of each measure for fitness to safe driving, simple correlations of

Table IIa. Mean and standard deviation of predictor variables among patients who resumed driving ($n = 31$).

	Values	
Variables	Mean	*SD*
Medico-functional measures		
Motor FIM-FAM		
Transfers		
Item 10	6.81	0.48
Item 11	6.84	0.46
Item 12	6.74	0.51
Item 13	6.78	0.50
Locomotion		
Item 14	6.74	0.51
Item 15	6.71	0.53
Item 16	6.55	0.68
Neuropsychological and cognitive measures		
VST	2.68	1.30
WAIS-R SDS	8.48	3.63
Cognitive FIM-FAM		
Item 26	5.94	0.68
Item 27	6.42	0.67
Item 28	6.61	0.62
Item 29	6.19	0.79
Item 30	6.10	0.60
Pre-TBI-habits and psychosocial measures		
Pre-TBI-risky personality index	12.84	3.03
Pre-TBI-risky-driving style index	9.13	3.34
Psychosocial FIM-FAM		
Item 22	6.23	0.67
Item 23	5.81	0.70
Item 24	6.03	0.71
Item 25	6.03	0.60

Table IIb. Descriptive statistics (frequencies, percentages, mean, and standard deviation) of the driving outcome measure ($n = 31$).

Number of post-TBI accidents and violations	Number of subjects involved (%)	Mean	*SD*
0	20 (64.5%)	0.48	0.77
1	8 (25.8%)		
2	2 (6.5%)		
3	1 (3.2%)		
Total	31 (100%)		

Table IIIa. Correlations between FIM–FAM motor items ($n = 31$).

	FIM Bed, chair, wheelchair	FIM Toilet	FIM Tub, shower	FAM Car indoor	FIM Walk, wheelchair	FIM Stairs	FAM Car driving, pub. transp.
FIMBed, chair, wheelchair	1						
FIM Toilet	0.927	1					
FIM Tub, shower	0.740	0.814	1				
FAM Car indoor	0.793	0.866	0.807	1			
FIM Walk, wheelchair	0.876	0.814	0.748	0.677	1		
FIM Stairs	0.826	0.770	0.818	0.757	0.941	1	
FAM Car driving, public transport	0.650	0.624	0.709	0.679	0.709	0.741	1

All correlations are significant at $p < 0.001$ two-tailed.

Table IIIb. Correlations between FIM-FAM cognitive items ($n = 31$).

	FIM Problem solving	FIM Memory	FAM Orientation in space and time	FAM Attention	FAM Safety judgement
FIM Problem solving	1				
FIM Memory	0.718	1			
FAM Orientation in space and time	0.655	0.728	1		
FAM Attention	0.828	0.781	0.774	1	
FAM Safety judgement	0.590	0.560	0.559	0.663	1

All correlations are significant at $p < 0.001$ two-tailed.

Table IIIc. Correlations between FIM-FAM psychosocial items ($n = 31$).

	FIM Social interaction	FAM Emotional status	FAM Adaptability to limitations	FAM Employability
FIM Social interaction	1			
FAM Emotional status	0.734	1		
FAM Adaptability to limitations	0.831	0.751	1	
FAM Employability	0.641	0.642	0.622	1

All correlations are significant at $p < 0.001$ two-tailed.

predictors with the outcome measure were calculated (Table IV).

Most correlations were not significant. None of the medico-functional variables, nor the neuropsychological test or the cognitive measures were significantly related to the number of accidents and violations after TBI. Therefore, LOC, which was the only predictor distinguishing between post-TBI drivers and non-drivers, was not relevant with respect to post-injury driving safety. Among demographic measures, significant correlation of years post-injury indicated the effect of time spent on the road in predicting car crashes or violations. This suggests that post-TBI drivers still remain an unsafe group even years after their return to driving. Accidents and violations before TBI (from driving records), pre-TBI-risky-personality index and pre-TBI-risky-driving-style index (from pre-TBI habits and psychosocial measures) were the most promising predictors of post-injury driving safety. Each of the three predictors correlated to the outcome measure in the expected direction, and all pointed toward a relevant role of patients' pre-TBI histories. The percentage of variance explained by these four measures, individually considered, ranged from 21% to 51% of the total variance.

Finally, the difference, in terms of number of post-TBI accidents and violations, between patients who resumed driving under medical consensus and those who did so without any medical agreement, did not turn out to be significant ($F\ (1, 29) = 0.171$, $p = 0.68$).

Predictive power of combined multiple measures

The final step of analysis was to combine predictors significantly correlated with the driving outcome measure, thereby increasing the amount of variance

Table IV. Simple correlations of predictor variables with the driving outcome measure ($n=31$).

Predictors	Post-TBI accidents and violations: Pearson r	p	r^2
Demographic and driving records			
Age at interview	−0.027	ns	
Age at TBI	−0.142	ns	
Year post-injury	0.458	0.01	0.21
Education	0.138	ns	
Age at licence achievement	−0.162	ns	
Years of driving before TBI	−0.103	ns	
Accidents and violations before TBI	0.716	0.000	0.51
Medico-functional measures			
GCS	−0.119	ns	
LOC	0.041	ns	
Motor FIM-FAM	0.127	ns	
Neuropsychological and cognitive measures			
VST	−0.005	ns	
WAIS-R SDS	0.033	ns	
Cognitive FIM-FAM	0.106	ns	
Pre-TBI-habits and psychosocial measures			
Pre-TBI-risky personality index	0.577	0.001	0.33
Pre-TBI-risky driving-style index	0.571	0.001	0.33
Psychosocial FIM-FAM	0.211	ns	

Abbreviations: *ns* = not significant at $p<0.05$ two-tailed; r^2 represents the proportion of variance in the outcome measure that is accounted for by the single predictor.

Table V. Hierarchical multiple regressions of four predictors (years post-injury, pre-TBI accidents and violations, pre-TBI-risky personality index, and pre-TBI risky driving style index) with the driving outcome measure (post-TBI accidents and violations) ($n=31$).

Variables	r^2	Adjusted r^2	pr^2	F	df	p	r^2 Change
Model 1							
Years post-injury	0.210	0.183	0.21	7.702	1.29	0.01	-
Model 2							
Years post-injury	0.667	0.643	0.32	28.06	2.28	0.00	
Pre-TBI accidents and violations			0.58				0.457
Model 3							
Years post-injury	0.692	0.658	0.28	20.21	3.27	0.00	
Pre-TBI accidents and violations			0.45				
Pre-TBI risky personality index			0.07				0.025
Model 4							
Years post-injury	0.725	0.682	0.28	17.12	4.26	0.00	
Pre-TBI accidents and violations			0.35				
Pre-TBI-risky-personality index			0.06				
Pre-TBI risky-driving-style index			0.11				0.033

Adjusted r^2 ponders the proportion of variance explained in the outcome measure for the number of predictors entered in the regression model.
Abbreviations: pr^2 is the squared partial correlation.

explained. The results presented in the previous section showed as the most promising four predictors: years post-injury, pre-TBI accidents and violations, pre-TBI-risky-personality index, and pre-TBI risky-driving-style index. A hierarchical regression was conducted to examine the contribution of these four variables in predicting the number of car accidents and violations after TBI, taken as objective measure of patients' post-injury driving safety (Table V).

Years post-injury was entered in the first step to control for effect of time, and it accounted for 21% of variance in the outcome measure ($p=0.01$). In the second step, pre-TBI accidents and violations was entered adding 45.7% of explained variance ($t=6.2$, $p=0.0001$). When pre-TBI-risky-personality index was added to the model in the third step, it accounted for another 2.5% of variance. Even if this variable was only marginally significant ($t=1.47$,

$p = 0.07$) the global model clearly was ($p = 0.0001$). In the last step, with the addition of pre-TBI risky-driving-style index ($t = 1.77$, $p = 0.044$) the final model was still significant, explaining 72.5% of the variance in the number of post-TBI accidents and violations. Adding other variables did not significantly increase the predictive power of the model. Therefore, the best regression equation was: $Z_{\text{Post-TBI accidents and violations}} = 0.34\, Z_{\text{Year post-injury}} \times 0.492\, Z_{\text{Pre-TBI accidents and violations}} \times 0.164\, Z_{\text{Pre-TBI-risky-personality index}} \times 0.213\, Z_{\text{Pre-TBI risky-driving-style index}}$.

Discussion

Driving outcome of patients recovering from severe TBI was assessed in terms of driving status and driving safety. Driving status consisted of distinguishing between subjects who resumed driving after TBI and those who did not, whilst driving safety was evaluated calculating the number of car accidents and traffic violations which occurred after patients' return to driving.

Consistent with previous studies, nearly 50% of patients reported driving after TBI [1–8], and a third of these subjects sustained one or more car accidents or traffic violations in their post-TBI driving history. Thus, post-TBI drivers can be thought of as a higher risk group compared to the general population [5]. The positive correlation between years post-injury and post-TBI accidents and violations further indicated long-lasting dangerous driving behaviours over the years. Compared to non-drivers, subjects who resumed driving again were characterized by shorter LOC, showing the unique value of TBI severity in predicting future driving status. The relevant role of medical data is supported by other research that adopted different injury severity rating scales [7, 20, 26, 74]. In contrast with these same works, GCS score in the first 24 hours was unexpectedly unrelated to successful driving status. The involvement of only severe TBI cases, however, increased group homogeneity and decreased the variable's range, and thereby diminished the magnitude of differences between groups. In fact, all the subjects were positioned only within 6 points of the GCS (from 3 to 8). In contrast, there was no upper limit for LOC. This different range of variability between GCS and LOC could explain why only LOC (the medical measure with a higher range variability) distinguished between post-TBI drivers and non-drivers, and GCS did not. No other demographic variables (i.e. age, age at TBI, years post-injury, and education) or biographic driving-history variables (i.e. age at license achievement, years of driving before TBI, or number of car accidents and violations before TBI) were related to whether the patients resumed driving post-injury.

Development of reliable procedures to assess fitness to safe driving and predicting driving outcomes in the real world is nowadays a crucial step in the rehabilitation process of TBI persons. However, such a commonly adopted system does not yet exist, and available methods to check a patient's efficiency do not provide a sufficient guarantee of the actual capabilities of driving safely. In fact, not even medical consent turned out to be a good predictor of driving outcome, and the recommendations of clinicians did not appear to have much influence on the final decision as to whether or not the patients resumed driving activities [8]. The majority of experimental reports over the last decades has focused on the idea of predicting fitness to drive by tests and measures bearing on rather elementary and basic functions. In this study, 16 predictors derived from four domains (demo-biographic, medico-functional, neuropsychological, and psychosocial) have been validated against post-TBI number of accidents and violations. We tried to consider all three levels entailed in driving properly (operational, tactical and strategic) and to adopt an outcome measure with great ecological and external validity. The results showed that accidents and violations before TBI, pre-TBI-risky-personality index and pre-TBI-risky-driving-style index were significantly related to post-injury driving safety and accounted for a proportion of variance in the outcome measure ranging from 21% to 51%. Predictive power was improved by combining these three variables with years post-injury. The final multiple regression model explained 72.5% of variance in number of post-TBI accidents and violations.

As expected, fitness to safe driving was more accurately predicted by variables concerning higher-order psychosocial and complex cognitive capabilities than by measures bearing on basic functions. According to Michon's model [54, 55], measures relating to the strategic level assess risk acceptance which, in turn, entails complex evaluations and comparisons between external conditions and fitness to cope with possible consequences. Consequently, feeling overconfident, even without severe basic disabilities, can lead to very risky behaviours. On the other hand, being aware of one's own deficits and acting accordingly can moderate accident risk, in spite of severe functional impairments.

The present study verified for the first time the speculations put forth by Boake and colleagues [5] who suggested that increased crash rates post-injury may be related to pre-injury driving habits and personality. In fact, all three measures correlated to driving outcome addressed different aspects of patients' pre-TBI histories. TBI is known as an event that originates dramatic changes in cognition, personality and character traits that are commonly considered the major problem even years after the injury occurred [35–43, 45, 46, 77]. A crucial distinction posed by Lishman [87, 88] differentiates between personality and behavioural changes due to direct, as opposed to indirect effects of brain injury. Direct effects result from lesions of neural tissues, while the latter are due to more heterogeneous factors such as subjective reactions to impairments, environmental conditions, and premorbid personality. Although the relative contributions of these two factors are far from clear and are difficult to tell apart, recent studies have stressed the influence of premorbid psychosocial background and habits on post-TBI functioning and behaviour [35, 89]. For example, Tate [35] reported that subjects with higher post-TBI loss of emotional control had higher pre-TBI scores on the same measure when compared to other TBI control subjects. The positive relationship observed in this study of premorbid personality traits and pre-TBI driving style with post-TBI driving behaviour further supports a view that behavioural and personality changes post-injury are partially considered as enhancements of previously existing traits. Thus, character changes, that are common sequelae of TBI, would be the result either of a qualitative transformation of the personality 'à la Phineas Gage', or of quantitative modification of pre-existing features. The relative influence of these two factors is still unclear, and perhaps varies among subjects, depending on various factors such as site, aetiology and severity of lesions.

Measures on patients' premorbid personality and pre-TBI driving style were derived from evaluations made by patients' close relatives or significant others. Given the subjective nature of these appraisals, it is difficult (or even impossible) to determine their objectivity and external validity: that is, whether these measures reflected patients' actual driving style and personality before injury, rather than inaccurate post-hoc relatives' opinions in that regard. In fact, by no means could we directly assess premorbid personality or verify whether close relatives evaluations reflected, for instance, real pre-TBI driving style. Prior research has shown that reports from caregivers on patients' functioning were more predictive of patients' fitness to drive than patients' self ratings [21, 39]. Other findings suggested that relatives' own personality structure could impact upon their perception of the effects of brain injury on patients [90]. From a theoretical perspective, it would be interesting to independently evaluate the external validity and objectivity of self-report measures. From a clinical point of view, however, there is not much difference between being sceptical rather than pragmatic about the external validity of self-report measures. Whatever position one takes, the afore-reported data is in any case interesting, and suggests that in order to allow a patient to return to drive, it is important to take into account the pre-TBI situation as reported by close relatives or significant others.

Contrarily to other works, the FIM-FAM measures in this study were unrelated to driving safety [7, 26]. Nonetheless, some studies have suggested that cognitive items are not sensitive enough to detect mild impairments in injured patients [91, 92]. Moreover, the effectiveness of FIM-FAM for monitoring long-term outcomes of injury is equivocal, and ceiling effects on this scale were reported 1 year post-injury [93, 94]. Therefore, FIM-FAM might not be sensitive enough when applied to the assessment of complex abilities such as those needed to drive safely.

Finally, neuropsychological tests addressing the tactical level did not predict driving outcomes in this study. Many studies using neuropsychological tests showed that these kind of measures were useful in assessing driving fitness [4, 9, 11, 16, 17, 19–21, 23, 27–32]. However, it should be noted that almost all these research studies used a different driving outcome measure from the one adopted here, generally consisting in an on-road evaluation. Compared to this latter parameter, the number of post-TBI accidents and violations is a very difficult factor to predict because of the great variability of the ecological context. Coleman and co-workers [21], who adopted an outcome measure quite similar to the present one, reported that neuropsychological performance only accounted for 8% of the variance. Furthermore, specifically developed neuropsychological tests turned out to be more sensitive in predicting driving fitness than generic tests tapping basic abilities [18]. It is probably too early to decide on the contribution of neuropsychological tests in assessing driving fitness. Nonetheless, we agree with those authors who put forward that an integral evaluation of the tactical level is provided by domain-specific neuropsychological tests combined with driving simulators or on-road evaluations [20, 32].

Conclusion

The present study involved subjects stabilized and recovered from traumatic brain injury with a relevant degree of functional decline. The aims were to contrast those patients who resumed driving after TBI with those who did not, and to validate a large range of measures in order to predict fitness to safe driving.

Taken together, the findings showed that the main distinguishing parameter between post-TBI drivers and non-drivers was the length of coma duration, indicating a unique role of injury severity in determining driving status. Best predictors of driving safety, measured in number of post-TBI car accidents and violations, were years post-injury, accidents and violations before TBI, pre-TBI-risky personality index, and pre-TBI-risky-driving-style index. These four parameters taken together predicted 72.5% of the variance in the outcome measure. These results suggest that in order to formulate more realistic and accurate evaluations on the actual possibility of driving safely after TBI, it would be advisable to consider carefully patients' pre-TBI histories, as reported by close relatives or significant others. Further research should be directed at assessing driving fitness and establishing commonly used evaluation procedures. It seems clear, however, that the predictive power and the effectiveness of such an evaluation procedure will be increased by considering not only operational, but also tactical and strategic levels.

Acknowledgements

This work was partially supported by a grant from the Ordine Mauriziano di Torinoto to Marco Tamietto. Thanks to Andrea Raviolo for his help in editing the manuscript.

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