Published in : Journal of Head Trauma Rehabilitation (2012), vol. 27, n°4, pp. 302-313
DOI: 10.1097/HTR.0b013e3182236299
Status : Postprint (Author's version)

Prediction of Driving Capacity After Traumatic Brain Injury: A Systematic Review

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KEYWORDS: cognitive, behavior, driving, head injury, head trauma, prognosis, risk factors, road safety

ABSTRACT

Objective: To review the current evidence on predictors for the ability to return to driving after traumatic brain injury.

Methods: Systematic searches were conducted in MEDLINE, PsycINFO, EMBASE, and CINAHL up to March 1, 2010. Studies were rigorously rated for their methodological content and quality and standardized data were extracted from eligible studies.

Results: We screened 2341 articles, of which 7 satisfied our inclusion criteria. Five studies were of limited quality because of undefined, unrepresentative samples and/or absence of blinding. Studies mentioned 38 candidate predictors and tested 37. The candidate predictors most frequently mentioned were "selective attention" and "divided attention" in 4/7 studies, and "executive functions" and "processing speed," both in 3/7 studies. No association with driving was observed for 19 candidate predictors. Eighteen candidate predictors from 3 domains were associated with driving capacity: patient and trauma characteristics, neuropsychological assessments, and general assessments; 10 candidate predictors were tested in only one study and 8 in more than one study. The results of associations were contradictory for all but one: time between trauma and driving evaluation.

Conclusions: There is no sound basis at present for predicting driving capacity after traumatic brain injury because most studies have methodological limitations.

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For many individuals, driving is a crucial activity of daily living.[1] Restrictions on driving are of major concern,[2] and the return to driving after trauma is a key event in reintegration into a normal lifestyle.[3]

Driving is a complex task that requires the integration of visual-perceptual stimuli, good judgment, decision making, and appropriate motor responses. It is well established that after traumatic brain injury (TBI)— especially those of moderate or greater severity—people experience cognitive and behavioral difficulties that may compromise their ability to resume driving safely. Deficits in attention, executive functions, and memory are the most significant residual deficits after TBI. Different aspects of attention deficit have been observed after TBI, including decreases in information-processing speed, working memory, and focused and selective attention.[4–6] The dysexecutive syndrome after TBI may include deficits in flexibility,[7] inhibition,[8] planning,[9] updating the contents of working memory,[10] reasoning,[4] awareness,[11] and cognitive control,[12] that is, "the ability to orchestrate thought and action in accord with internal goals."[13] Moreover, TBI survivors may exhibit affective and behavioral changes including aggression, impulsiveness, irritability, emotional instability, and apathy.[14,15] Post -TBI drivers have been considered a high-risk group compared with the general population.[16]

Although these cognitive and behavioral difficulties may compromise the fitness to drive, between 40% and 80% of patients do return to driving after TBI, and the ability to drive safely is not tested formally in almost two-thirds of cases.[17] Identification of valid predictors of safe driving after TBI is important because returning to driving may endanger both the patient and other road users. Such predictors could help in specifying rehabilitation needs and could be used to guide clinical decision making.[18]

Few studies have attempted to identify predictors of safe driving after TBI, and no systematic review including all predictors reported has been performed. The best method of predicting fitness to drive after TBI is yet to be determined.[19] The aim of this review was to determine whether studies of predictors of fitness to drive after TBI are methodologically valid, and if so, to identify factors that may help clinicians judge driving ability.

METHODS

SYSTEMATIC LITERATURE SEARCH

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Searches were conducted in MEDLINE, PsycINFO, EMBASE, and CINAHL up to March 1, 2010. We used a low-sensitivity, high-specificity approach, that is, we conducted a broad-based search using the follow terms: *Traumatic brain injury* or *head injury* and *drive* or *driving*; in MEDLINE the following: *Traumatic brain injury* or *head injury* and *drive* or *driving* and *risk factor* or *predictor* or *abbreviated injury score* or *behavior* or *cognitive* or *age* or *Glasgow Coma Scale* or *coma*. Although such a broad search resulted in many articles out of topic, it was the best way to minimize overlooking publications.

The titles of all articles were independently screened by 3 authors (C.O., C.B., B.W.) to identify reports potentially meeting our inclusion criteria. The abstracts of all reports first selected for inclusion were read independently by the same 3 authors. If the study methods were not obvious from the abstract, the full text of the article was examined. Disagreements among the reviewers regarding inclusion or exclusion were resolved by consensus. The full texts of all studies meeting our inclusion criteria were then retrieved and reviewed.

We included only full publications; meeting abstracts and letters were excluded. The bibliographies of retrieved reports and relevant review articles were checked for additional articles. We included studies that met the following criteria: (a) the sample included adult survivors of any severity of TBI; (b) the article reported the results of a cohort study with statistical analyses appropriate to a prognostic study, that is, multivariate analyses controlling for covariates (group comparisons only were excluded); and (c) the outcome variable was the ability to drive. If the sample included mixed injuries, at least 80% of the patients had to have a diagnosis of TBI or the results for the TBI group had to be presented separately. Criterion (b) was chosen to ensure that studies included had valid prognostic methods[18] and that the systematic review offered the best available scientific evidence.

DATA ABSTRACTION AND DEFTNITIONS

Data were extracted independently by 2 authors (C.O., C.B.) from each report using a standardized datasheet comprising the following: study population, sample size, type of collection (prospective, retrospective), variables considered for and entered into statistical analysis, time between trauma and data collection of the dependent variable (driving), statistical procedures and results, and individual variables that significantly contributed to the statistical analysis. Outcome measures, type of statistical analysis, data about the traumatic event, and comments were also documented for each study.

Many neuropsychological tests were used as variables to predict driving ability in these studies. We grouped these investigations and allotted them group names, for example, all executive tests were grouped and entitled "executive functions."

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ASSESSMENT OF STUDY QUALITY AND ANALYSIS

The quality of the methodology of the studies included was rated on the 6-item scale established by Pengel et al.[20] Qualitative criteria were as follows: (a) representative sample; (b) defined sample, including the source of participants and inclusion and exclusion criteria; (c) follow-up of more than 79% on the outcome variable; (d) provision of raw (descriptive) data for most prognostic variables; (e) assessor masking for at least one prognostic variable; and (f) use of statistical methods appropriate to a prognostic study, including accounting for covariates. We added a seventh item for study design: prospective or not.

The methodological quality was rated by all investigators. Each criterion had to be explicitly identified in the article and 1 point was awarded for each that was present. Discrepancies were resolved at meetings held for this purpose. The maximum score was 6 using the 6-item scale of Pengel et al,[20] and the minimum score was 0. Six points meant excellent methodological quality and indicated that the results could be considered with confidence. A score of zero meant very low methodological quality; this low ranking suggests that interpretation of the results is challenging.

The data from the different studies were not pooled because they used a large and heterogeneous set of prognostic variables and a wide range of statistical procedures.

RESULTS

STUDIES INCLUDED

Our database searches yielded 2341 articles; most re- ports were unrelated to our topic, and 14 categories of excluded reports were established (Figure 1). Seventy- three reports were of potential interest and were further investigated; 66 reports were excluded for different rea- sons (Tables 1 and 2).[2,17,19,21–83]

Seven reports therefore met our inclusion criteria.[3,16,84–88] All studies were observational and had been conducted in Canada, Italy, Belgium, United States (Alabama, Missouri, Los Angeles), and the Netherlands. The sample sizes ranged from 10 to 71 patients (Table 3), and most patients were men. Five studies included patients with TBI only. The mean age when driving capacity was evaluated was between 29 and 40 years. In 6 of the 7 studies, the driving capacity was evaluated >1 year after TBI. Severity of TBI was described by 2 items (Glasgow Coma Scale [GCS], coma duration); GCS was used in 2 studies, coma duration in 2 studies, and both in 1 study. Two studies did not report severity information.

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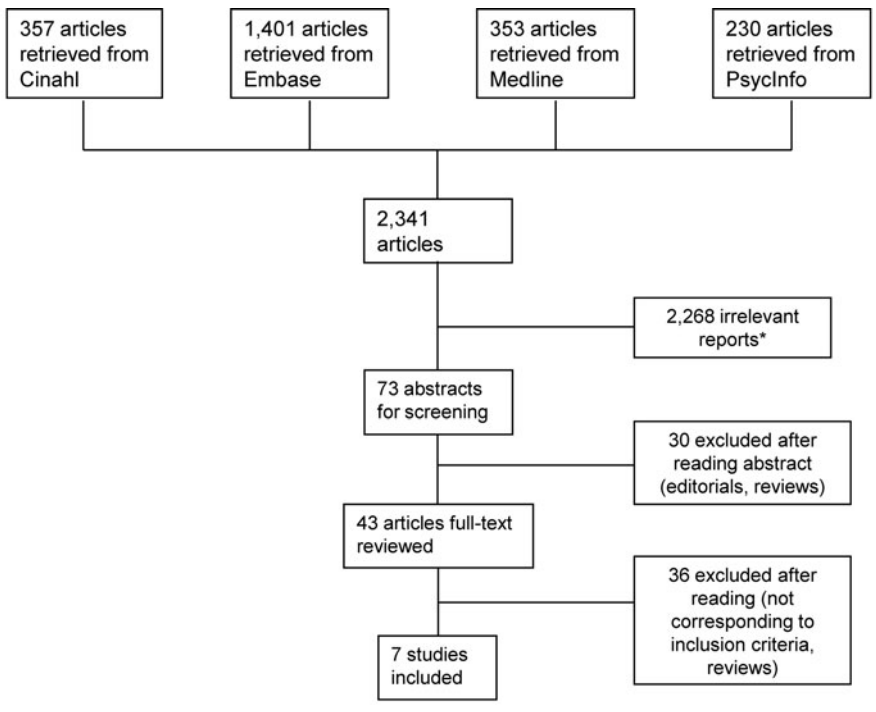
ASSESSMENT OF STUDY QUALITY

The mean (± standard deviation) methodological rating score of the studies included was 4.4 ± 0.8 (range 4-6) (Table 4). Six studies were prospective and 6 had ad- equate follow-up of patients. All studies had appropriate statistical analyses. Five studies were of limited quality because of undefined or unrepresentative samples and the absence of assessor blinding.

Figure 1. *Literature search and flow chart of inclusion and exclusion.*



* Categories of irrelevant reports: animal studies (7%), experimental molecular research (11%), neuroimaging (2%), neurophysiopathology (6%), drug trial (1%), visual impairment (4%), neuropsychology outside of driving (16%), neuropsychological testing without TBI patients (4%), virtual driving (2%), epidemiology of injury (32%), prevention of injury (8%), diagnosis of coma (3%), mechanism of TBI (3%), case reports (1%).

CANDIDATE PREDICTORS OF DRIVING ABILITY

Between 3 and 17 candidate predictors of driving ability after TBI were reported per study, resulting in 38 variables across the 7 studies (Table 5). We identified 3 clusters of candidate predictors: the first cluster "patient and trauma characteristics" (n = 12) included data on patients, trauma

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characteristics, and information on the patient's driving experience before TBI (eg, age on achieving license, level of expertise, number of accidents, and violations). The second cluster—"neuropsychological assessment after TBI"—included neuropsychological tests (n = 16), and the third cluster—"general evaluations after TBI"—included general evaluations made after TBI (eg, driving simulation, knowledge of driving rules, self- awareness, level of functional limitation, n= 9). No single candidate predictor was used in all studies. The candidate predictors mentioned most frequently were "selective attention" and "divided attention" in 4 of the 7 studies, and in 3 of the 7 studies, each "executive functions" (inhibition, shifting, and planning) and "processing speed." All studies included neuropsychological tests as candidate predictors.

OUTCOME ASSESSMENT—DRIVING CAPACITY

The 7 studies reported on 4 different outcome measures of driving capacity. The first (4 of the 7 studies) was a driving-on-road evaluation with an expert and was different across the 4 studies: (a) unstructured open-road driving in a busy traffic environment with performance rated on a defined checklist[16]; (b) an on-road test on private and public roads with performance estimated by a team[85]; (c) a 17-km standard route with performance estimated by an experienced driving school instructor[87]; and (d) on-road driving with different degrees of difficulty rated by a driving evaluator based on the Driving Assessment Scale.[88]

Table 1 *- References of excluded reports based on abstract reading with reason for exclusion*

Study without predictors
Brouwer W. Cortex. 1989;25:219–230.
Coleman RD. ETD Collection for Wayne State University. 2000.
Formisano R. *Eura Medicophys*. 2001;37:257–266.
Galski T. *Am J Occup Ther*. 1997;51:352–359. HuchlerS.*EuraMedicophys*.2001;37:283–289.
Katz RT. *Arch Phys Med Rehabil*. 1990;71:133–137.
Olver JH. *Brain Inj.* 1996;10:841–848.
Ratte J. *Eura Medicophys*. 2001;37:279–281. Riese H. *Neuropsychol Rehabil*. 1999;9:189–205.
Schultheis MT. *J Head Trauma Rehabil*. 2002;17:38–47.
Schultheis MT. *Conf Proc IEEE Eng Med Biol Soc*. 2006;1:4921–4924.
Schultheis MT. *Assist Technol*. 2007;19:1–8.
Wald J. *Stud Health Technol Inform*.2000;70:365–367.
Williams A. *OT Pract*. 1999;4:63–64.
Prediction in an unspecific population
Innes C. *Conf Proc IEEE Eng Med Biol Soc*. 2005;5:5439–5442.
Kay LG. *Am J Occup Ther*. 2008;62:187–197.
Lengenfelder J.*J Head Trauma Rehabil*. 2002;17:26–37.
Letts L. *Assist Technol*. 2007;19:154–163.
PatomellaA.*Scand J Occup Ther*.2004;11:70–77.
Patomella A. *Scand J Occup Ther*. 2008;15:184–192.
Epidemiology

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Klein Hofmeijer AMJ. *Eura Medicophys*. 2002;38:29–32.
Mosberg A. *Tidsskr Nor Laegeforen*. 2000;120:3392–3395.
Newby G. *Br J Gen Pract*. 1999;49:301–302.
Ponsford AS. *Lakartidningen.* 1998;7:71–73.
Review
Brouwer W. *Neuropsychol Rehabil*. 1997;7:177–193.
Debelleix X. *Eura Medicophys*. 2001;37:201–208.
Hopewell CA. *J Head Trauma Rehabil*. 2002;17:48–61.
Mazzucchi A. *Eura Medicophys*. 2001;37:267–273.
Editorial
Dobkin B. *Curr Opin Neurol*. 1998;11:639–641. Prevention
Hassall M. *Br J Neurosci Nurs*. 2008;4:163–165. Inadequate statistic for prediction
None
Visual impairment
None

Table 2 *- References of excluded reports based on full text reading with reason for exclusion*

Study without predictors
Brooke M. *Am J Phys Med Rehabil*. 1992;71:177–182.
Christie N. *Neuropsychol Rehabil*. 2001;11:45–55.
Cyr A. *J Clin Exp Neuropsychol*. 2008;1:1-11.
Galski T. *Am J Occ Ther*. 1992;46:324-332.
Galski T. *Am J Occ Ther*. 1993;47:391-396.
George S. *Aust Occ Ther J*. 2008;55:172-179.
Gianustos R. *Assist Technol*. 1992;4:70-86.
Haselkorn J. *Arch Phys Med Rehabil*.1998;79:738-742.
Lew H. *Brain Inj*. 2005;19:177-188.
Liu L. *Cyberpsychol Behav*. 1999;1:53-67.
Lundqvist A. *Brain Inj*. 2007;21:1109-1117.
Martelli S. *Eura Medicophys*. 2001;37:245-255.
Priddy D. *Brain Inj*. 1990;4:267-272.
Radford K. *Brain Inj*. 2004;18:775-786.
Rapport L. *J Head Trauma Rehabil*.2006;21:34-44.
Rapport L. *Arch Phys Med Rehabil*.2008;89:922-930.
Schanke A. *Tidsskr Nor Loegeforen*. 1999;7:954-958.
Schanke A. *J Rehabil Med*.2008;40:733-736.
Van Zomeren A. *Arch Phys Med Rehabil*.1988;69:90-96.
Wald J. *Cyberpsychol Behav*. 2000;3:643-654.
Prediction in an unspecific population
Brouwer W. *J Head Trauma Rehabil*. 2002;17:1-15.
Elkin-Frankston S. *Arch Clin Neuropsychol*.2007;22:631-635.
Hannen P. *Nervenarzt*. 1998;69:864-872.
Innes C. *J Neurol Sci*. 2007;260:188-198.
Schanke A. *Scand J Psychol*.2000;41:113-121.
Yale S. *Clin Med Res*.2003;3:17–188.
Epidemiology
Fisk G. *Brain Inj*. 1998;12:683-695.
Review
Brooks N. *Brain Inj.* 2005;19:165-175.
Unsworth C. *Aust Occ Ther J*. 2005;52:57-74.

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Van Zomeren A. *Arch Phys Med Rehabil*. 1987;68:697-705.
Editorial
None
Prevention
Leon-Carrion J. *Brain Inj*. 2005;19:213-219.
Inadequate statistic for prediction
Dimarco F. *Europa Medicophysica.* 2001; 37:215-25.
Lundqvist A. *Brain Injury*. 2008; 22:295-304. S
chultheis M. *Rehabil Psychol.* 2003;48:275-280.
Sivak M. *Arch Phys Med Rehabil*. 1981;62:476-83.
Visual impairment
Schulte T. *Am J Phys Med*. 1999;78:136-142.

Table 3 *- Characteristics of the 7 studies included*

Prediction of Driving Capacity After Traumatic Brain Injury

First Author (year of publication)	Gouvier WD (1989)	Korteling JE (1996)	Strypstein E (2001)	Coleman RD (2002)	Pietrapiana P (2005)	Bouillon L (2006)	Novack TA (2006)
Study population	TBI, spinal injured, controls	TBI	TBI	TBI (+proxy)	TBI (+proxy)	Neurological case-mix	TBI
Sample size	25 (10 TBI)	38	54; 24 (fit[a]), 30 (unfit[b])	71 (+71 pairs)	66 (+66 pairs); 31 drivers after TBI	172 (58 TBI)	60
Gender (male/female; % male)	7/3 70	33/5 86.8	Not specified; 100 (fit[a]), 83 (unfit[b])	57/14 80.3	54/12 81.8	Not specified for TBI	38/22 63.3
Age at TBI (y; mean, [SD], min-max)	Not specified	29.8 [10.9] 17-55	Not specified	Not specified	28.7 [9.2] 15-60	Not specified	Not specified
Age at investigation (y; mean, [SD], min-max)	29,3; 18-48	Not specified	33 [12] (fit[a]) 28 [10] (unfit[b])	40.2 [13.0] 17-77	34.4 [9.4] 21-62	Not specified for TBI	33 16-68
Time postinjury (y; mean, [SD.], min-max)	Not specified	at least 1	1.2 [1.7](fit[a]) 4 [4.6] (unfit[b])	0.3-10	5.6 [3.7] 1-16	Not specified for TBI	1.5-19
GCS (mean, [SD], min-max)	Not specified	Not specified	Not specified	10.7 [3.5] 3-12	5.9 [1.9] 3-8	Not specified	0-8 (72%)[c] 9–12 (18%)[c]
Coma duration (d; mean, [SD], min-max)	75.8 0–300	33 [51]	Not specified	Not specified	12.4 [8.2]	Not specified	Not specified
Driving license before injury (%)	100	100	83 (fit[a]) 70 (unfit[b])	Not specified	not specified	Not specified	100
Age when achieved license (y; mean, [SD], min-max)	Not specified	Not specified	Not specified	Not specified	18.9 [1.6] 18-24	Not specified	Not specified
Experience of driving before TBI (km or y; mean, [SD], min-max)	10.6 y 0-32 y	109 000 km [86 300 km]	Not specified	Not specified	10.3 y [8.5 y]	Not specified	Not specified

[a]Fit = judged as able to drive at the end of evaluation.
[b]Unfit = judged as unable to drive at the end of evaluation.
[c]Becker conversion.

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The second outcome measure was a driving evaluation on a secured area (1 study): an expert assessed the patients' performance in driving a modified full-sized vehicle around a closed course, with 8 maneuvers evaluated by 2 raters, one in the vehicle, the second observing from the course.

The third outcome measure was an interview withthe proxy about the patient's post-TBI driving performance (1 of the 7 studies): a semi-structured interview was conducted to obtain data on the patient's current driving behavior, including the average number of miles driven weekly, and official driving records were requested from the Department of Motor Vehicles.

The fourth outcome measure was the driving status (driver or nondriver), together with numbers of accidents and violations after TBI.

Table 4 *- Methodological quality of the studies included*

First author (year of publication)	Gouvier WD (1989)	Korteling JE (1996)	Strypstein E (2001)	Coleman RD (2002)	Pietrapiana P (2005)	Bouillon L (2006)	Novack TA (2006)
Representative sample (random or consecutive)	0	0	0	0	0	1	0
Defined sample (inclusion/ exclusion criteria)	0	0	0	1	0	0	0
Follow-up of >79%	1	1	1	1	0	1	1
Raw descriptive data	1	1	1	1	1	1	1
Assessor blinding	0	0	0	0	0	1	1
Appropriate statistical methods	1	1	1	1	1	1	1

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Prospective	1	1	0	1	1	1	1
Total	**4**	**4**	**3**	**4**	**4**	**6**	**5**

CANDIDATE PREDICTORS ASSOCIATED WITH DRIVING CAPACITY

The findings for 37 of the 38 candidate variables were reported; for one variable (driving records) no association was searched (4-6Table 5). Nineteen candidate predictors were not associated with driving after TBI. Astatistical association was found for 18 candidate predictors: 7 of the 12 variables included in "patient and trauma characteristics," 8 of the 16 variables in "neuropsychological assessment after TBI," and 3 of the 9variables under "general assessments after TBI."

Eight candidate predictors associated with driving capacity were included in 2 or more studies: age at investigation, time postinjury, coma duration, executive functions, selective attention, divided attention, processing speed, and visual perception. Only one candidate predictor had significant associations in the 2 studies in which it was included: time between trauma and driving evaluation. The results of the associations differed for all other candidate predictors across the 7 studies. Associations were observed in 2 of the 4 studies for 2 candidate predictors: divided and selective attention; in 1 of the 2 studies for 3 candidate predictors: age at investigation, coma duration, visual perception; and in 1 of the 3 studies for 2 candidate predictors: executive functions and processing speed.

Ten candidate predictors associated with driving capacity were mentioned in one study only: accidents and violations before TBI, pre-TBI risk personality, pre-TBI risk driving style, driving experience, perceptual speed, neuropsychological composite score, cognitive behavioral driver's capacity inventory, driver performance test, Patient Competency Rating Scale, and Disability Rating Scale.

All authors commented on limitations of theirstudies except Coleman et al[86] and Strypstein et al.[85] Three studies mentioned the limited sample size[16,84,88] and 3 mentioned limitations related to tests used.[3,16,87] Two studies reported that their outcome measures might not have been reliable.[16,87]

DISCUSSION

4-6Our systematic literature search identified 7 studies meeting our selection criteria that reported on prognostic factors for the ability to return to driving after TBI. Most studies had methodological limitations related to sampling and blinding. Many candidate predictors were tested, but only in

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small cohorts, and none were used in all studies. There is therefore still no sound basis for the predicting driving capacity after TBI.

STRENGTHS AND LIMITATIONS OF OUR SYSTEMATIC REVIEW

We used a rigorous, systematic, and transparent review method to search and assess the relevant literature. The extremely large number of studies initially identified but subsequently eliminated suggests that we did, indeed, cast a very large net. Despite this, it is still possible that eligible studies, in particular if not indexed in the literature databases used, might have been missed. Our appraisal of study quality and relevance of findings was on the basis of established scoring and assessment systems.[20,89] We focused on the available evidence from research studies and excluded other types of information.

METHODOLOGICAL LIMITATIONS OF STUDIES INCLUDED

The methodological quality of the studies included was rated on a modified scale established by Pengel et al.[20] Most of the studies had methodological limitations that may induce bias in the prognostic accuracy of fitness to drive and had weaknesses in 3 aspects: sample size, defined and representative samples, and blinding and standardization of outcome assessment.

Most studies had small sample sizes. This was mentioned as a limitation by some authors. A cohort with few participants and a large number of candidate predictors may decrease the validity of predictive models, and a predictive variable may not be robust during external validation.[90,91]

Table 5 *- Candidate predictors investigated (0 = no risk factor, 1 = risk factor, blank = not investigated). Reports included: 1, Gouvier WD (1989); 2, Korteling JE (1996); 3, Strypstein E (2001); 4, Coleman RD (2002); 5, Pietrapiana P (2005); 6, Bouillon L (2006); 7, Novack TA (2006)*

	Studies Reporting on a Candidate Predictor Without Association	**Studies Reporting on a Candidate Predictor With Association**
Patient and trauma parameters		
Education	*5*	
Age at TBI	*5*	
Age at investigation	*5*	*7*
Time between trauma and driving evaluation		4;5
GCS		4;5
Coma duration 5 2	*5*	*2*
Age at license achievement	*5*	
Time of driving before TBI	*5*	

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Accidents and violations before TBI		*5*
Pre-TBI- risky personality (index)		*5*
Pre-TBI- risky driving style (index)		*5*
Driving experience		*2*
Neuropsychological assessment after TBI		
Reasoning (matrices, picture arrangement)	*1*	
Executive functions (TMT B, TEA[a] Rey copy)	*1;3*	*7*
Visuoconstructive capacity (Rey copy)	*3*	
Perceptual speed (quick visual decision)		*2*
Processing speed (WAIS symbol-digit)	*2;5*	*1*
Selective attention (TEA,[a] TMT A, UFVT[b])	*5;7*	*1;3*
Divided attention (TEA,[a] UFVT,[b] Tracking Reactionc)	*3;5*	*2;7*
Time estimation	*2*	
UFVT[b]	*3*	
Hemi-neglect (Bells test, TEA[a])	*3;6*	
Visual perception (AVPA,[d] TEA[a])	*1*	*3*
Motor-free visual perception test (evaluation of visual perception independent of motor ability)	*1;6*	
Working memory (WAIS block design and arithmetic)	*1*	
Visual reaction time (REACT,[e] UFVT[b])	*1;7*	
Neuropsychological composite score (WAIS letter-number sequencing,CTA and B, matrices)		*4*
Cognitive behavioral driver's inventory[f]		*6*
General evaluations after TBI		
Tracking simulator (evaluation of driving maneuvers)	*1*	
Driving on secured area (small-scale vehicle)	*1*	
Driver performance test (evaluation of driving knowledge)		*1*

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Brake reaction time	*7*	
Patient Competency Rating Scale (evaluation of self-awareness)		*4*
Social Provision Scale (evaluation of perceived social support)	*4*	
Disability Rating Scaleg		*4*
Functional Independence Measure (assessment of daily living)	*5*	
Functional Assessment Measure (assessment of daily living)	*5*	

[a]TEA: computerized evaluation of attention and executive functions.

[b]Useful field view test: evaluation of visual attention.

[c]Tracking reaction: computerized task where subjects had to keep their own vehicle in the middle of a lane while monitoring the position of traffic on a side-road that disappeared behind a wall.

[d]Adult Visual Perceptual Assessment: evaluation of visual perception including sub-scores (Figure Ground, Form Constancy, Position in Space, Depth, and Spatial Relations).

[e]REACT: Computerized task of visual reaction time.

[f]Cognitive behavioral driver's inventory 4 components from Bracy's Computer-Assisted Cognitive Rehabilitation (visual reaction differential response, visual reaction differential response reversed, visual discrimination differential response II and visual scanning III), WAIS picture completion and digit-symbol, TMT A and B, brake-reaction test, examination of visual field.

[g]Disability Rating Scale: assessment of the level of disability among TBI patients, examining the rehabilitation process from coma to community reintegration (4 categories: arousal and awareness; cognitive ability to handle self-care; physical dependence on others; psychosocial adaptation to work, school and home activities).

Most of the studies did not report inclusion or exclusion criteria or details of the severity of the TBI on hospital admission. The information on patient age at TBI, the age at which the patients obtained their driving licenses and their driving experience before TBI were often not reported. It was therefore not possible to ensure that the samples were representative; thus, in the absence of this, referral bias[92] and patient selection bias, related to trauma heterogeneity for example, could not be excluded. Bias of this type may affect diagnostic and prognostic accuracy,[93] and studies that involved non- representative patients or that used different reference standards tended to overestimate the diagnostic reliability of a test.[94] The absence of these variables limited the precision with which we were able to characterize the populations included and, therefore, considerably limited comparability. One set of patient characteristics, however, would be easy to

Published in : Journal of Head Trauma Rehabilitation (2012), vol. 27, n°4, pp. 302-313
DOI: 10.1097/HTR.0b013e3182236299
Status : Postprint (Author's version)

obtain and is highly relevant: the IMPACT study including the initial GCS, pupil response, computed tomography results and age in more than 8500 patients found that these variables can accurately predict score on the Glasgow Outcome Scale.[95]

Four of the 7 studies in this systematic review used "on-road driving" with an expert as an outcome, but this method of evaluation presents methodological problems. First, the expert was not blinded to patient data; the absence of assessor-blinding may over- or underestimate the outcome-related information.[96] Second, on- road evaluation cannot be standardized any may there- fore not be reliable[97] because of unpredictable traffic situations, and a change in driving instructor may result in different pass and fail rates.[98]

LIMITATIONS RELATED TO SELECTED PREDICTORS

The wide range of neuropsychological instruments used may reflect insecurity and absence of consensus in this setting, even though several tests showed some value in some assessments of driving capacity, particularly those involving focused and divided attention, processing speed, working memory, and perceptual-motor skills.[81–83] However, there was no consistency in the predictive validity of these instruments.

Only two studies investigated pre-TBI variables such as risk-taking personality, driving style, and anosognosia, and both reported an association between these variables and post-TBI driving capacity. None of the studies investigated posttraumatic behavior, even though this may compromise fitness to drive, and behavioral changes have frequently been observed after TBI,[99] including aggression, impulsivity, irritability, emotional instabibity and apathy.[14,15]

The type of rehabilitation may be associated with driving capacity but was not reported in the studies included. Some institutions offer specific driving training.[100] Instruction of this sort should be included as a candidate predictor in a prognostic model. The patient's social environment may also play a role in driving capacity, that is, the presence of a proxy while the patient is driving may influence the patient's driving capacity.

COMPARISON WITH EXISTING REVIEWS

In a narrative review with no details of literature searching, unknown and subjective inclusion criteria, and no assessment of the primary studies included, Tamietto et al[101] reported discrepant results related to 5 aspects: (1) the type of predriving predictors included in the analysis, (2) the variables considered as the criterion for the determination of fitness to drive, (3) the severity of TBI in the sample of patients studied, (4) the extent of neural structures damaged by TBI and the overlap of these areas with those involved in driving tasks, and (5) the length of follow-up. The

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authors concluded that the factors that can predict driving capacity after TBI are unclear, as is the way in which driving capacity should be assessed. The subjective view of the authors of this informal narrative review corresponds to our observations in our rigorous, systematic review with transparent methods and result reporting.

Classen et al[102] conducted a systematic review focused on neuropsychological, simulator, and other assessment tools predicting driving performance after TBI. Limited evidence was found that the assessment tools were suit- able for the prediction of performance. For the authors, the lack of evidence was related to methodological problems such as the small sample sizes and the absence of blinding. Our systematic review was broader and aimed to identify *all* types of predictors for return to driving in patients after TBI, but confirmed that major methodological limitations are present in all studies conducted, even using potential patient and trauma predictors.

CLINICAL DECISION MAKING

Data from prognostic studies are important because valid predictors are helpful in identifying therapeutic needs and can be used as a guide for clinical decision making.[100] Valid prognostic models after TBI are particularly important because the population is predominantly young. Driving, together with returning to work, is an important element in good quality of life. However, the studies included in this review had serious limitations and are therefore of limited value in deciding when or whether TBI patients can return to driving. Despite this, decisions have to be made, even if predictive factors are not valid. So, what is the best approach in such a difficult clinical condition with an uncertain outcome? It is obviously necessary to approach any decision with great caution, and evaluators must always bear in mind the risk of bias toward permitting post-TBI patients to drive who are actually not fit to. To reduce this risk, a second opinion from an expert or team of experts with experience in the field combined with guidelines from professional societies may assist with decision making. Such guidelines could be based on systematic reviews and expert opinions.

FURTHER RESEARCH

How can these methodological limitations be over- come in studies to validate the candidate variables designed to test the complex task of 'driving', including automatic and strategic processes?

1. A representative, large cohort with clear inclusion and exclusion criteria and few missing data should be studied.
2. The assessor of on-road driving should be blinded to preexisting patient data and should assess driving capacity with a standardized checklist. Driving evaluation in a simulated environment together with neuropsychological assessment may be a useful complement to the road tests.[103]

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Visual impairment, disordered attention, reduced processing of visual motion cues, and overall cognitive decline during driving simulation were identified as predictors of car crashes among patients with mild and moderate Alzheimer disease.[104,105] Similar testing may be valuable in assessing the fitness to drive in TBI patients. Traffic simulation should include different visual stimuli at the same time.

3. The GCS, pupil reaction, computer tomographic characterization of cerebral lesions, and age on hospital admission should be included as candidate predictors in the prognostic models, as used for more general outcomes after TBI.[106]
4. Cognitive, behavioral, and any neurophysical functioning of the sense organs should be tested comprehensively, including predictors related to the history of behavior before TBI, and should including time-stress elements.
5. Environmental variables such as rehabilitation conditions and family functioning should be tested in prognostic models.

In accordance with Bouillon et al,[87] such a comprehensive model with candidate predictors from different domains and from different times may increase the predictability of both crash-causing behavior and everyday driving capacity after TBI,[107] and may allow more accurate and discriminating prediction.

CONCLUSION

Conclusive evidence for the predictability of driving capacity in patients after TBI is lacking because of methodological drawbacks in studies and limitations related to selected potential predictors. We urge future researchers to employ comprehensive, standardized testing with a defined set of predictor variables.

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