

Predicting Factors of Driving Abilities after Acquired Brain Injury through Combined Neuropsychological and Mediatester Driving Assessment*

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The objective of the study was to evaluate predictor variables stemming from different assessment approaches (medical documentation, neuropsychological assessment, and Mediatester driving assessment) on patient's ability to drive (passing the practical driving test with a qualified instructor) following a TBI (traumatic brain injury) or a stroke. The study included 63 participants (54 males), aged 20 to 80 years ($M = 44.4$; $SD = 16.7$). Majority of participants suffered a TBI and 18 participants were included after an ischemic stroke. Patients who passed a driving test had significantly higher composite index on Comprehensive Trail-Making Test (medium or large effect size) compared to those who did not pass a driving test, or those who passed the driving test with limitations. The results on the 18-light reaction test (18 LRT) suggest that the reaction time could also play a role in predicting the ability to drive. The model with these two predictors, along with Glasgow Coma Scale, successfully classified 90 % of participants in two respectful groups; passed vs. did not pass a driving test/passed the driving test with limitations. The results suggest that neuropsychological and driving assessments that measure a range of cognitive abilities are better predictors of regaining the ability to drive after a TBI or stroke than separate cognitive abilities.

Keywords: neuropsychology, neurorehabilitation, driving, assessment, brain injury.

Highlights:

- We explored the the effect of medical documentation, neuropsychological assessment, and Mediatester driving assessment on the patient's ability to drive following TBI or stroke.

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- Neuropsychological tests of multiple cognitive abilities (processing speed and cognitive flexibility) have better predictive value for driving outcomes than measures assessing separate cognitive abilities.
- The combination of medical information, neuropsychological tests and Mediatester assessment successfully predicted the ability to drive assessed by a practical driving test.

The ability to drive is one of the most independence permitting abilities in a modern motorized community. Despite driving being a routine process, it never becomes entirely automated. As one of the more challenging cognitive tasks, driving ability is compromised as soon as any motor, cognitive, or perceptual abilities deteriorate. Most often we observe a sudden change in the ability with survivors of brain stroke, traumatic brain injury, or people with neurodegenerative disorders such as Multiple Sclerosis, Parkinson's disease or Alzheimer's disease (Devos et al., 2011).

Withaar, Brouwer, and Van Zomeren (2000) argue that driving mostly depends on attention and visual information processing. However, to successfully cope with traffic one also needs quick mental processing, forward thinking, decision making, judgment and adjusting to the ever-changing environment (Ortoleva et al., 2012). Deficits in attention are reflected in rapid disclosure, not recognizing the danger and inability to perform multiple tasks at once (Ortoleva et al., 2012; Schultheis & Whipple, 2014), which may constitute a major obstacle to the safe participation in road transport. Executive functioning deficits of inhibition, planning, abstract reasoning and self-awareness skills, can also affect the efficiency of driving performance (Ortoleva et al., 2012; Schultheis & Whipple, 2014).

In previous research, neuropsychological tests have been evaluated as a useful diagnostic tool for assessing the ability to drive (Pietrapiana et al., 2005). Tests that measure focused and divided attention, the speed of information processing, working memory and perceptual motor abilities have been proven as effective means for assessing the ability to drive (Coleman et al., 2002; Fox et al., 1992; Galski et al., 1992; Galski et al., 1990; Lundqvist, 2001; Rothke, 1989; Sivak, 1996; Van Zomeren et al., 1987). There is extensive literature suggesting that slowed processing speed represents a risk for safe driving (Clay et al., 2005; Odenheimer et al., 1994; Owsley et al., 1998; Wood et al., 2009). In a later review, Wolpe & Lehockey (2016) concluded that thorough assessment of attention, mental processing speed, visual perception, visual spatial abilities, and executive functioning is imperative for determining an individual's capacity to drive safely. However even a short battery of neuropsychological tests has shown predictive value with regard to the safe return to driving ability after severe brain injury. Significant correlations were found between attention, executive functions, overall visual-spatial exploration and driving performance (Saviola et al., 2018).

The Trail Making Test B has received much attention in the driving literature (Wolpe & Lehouckey, 2016). While some neuropsychologists consider the Trail Making Test Part B (TMT–B) to be a measure of complex processing speed, others consider this test to be a measure of executive functioning. Regardless, it mostly turns out to be an important predictor of the ability to drive. Novack and colleagues (2000) found that poor performance on the Trail Making Test Part B is a good predictor of the failure in driving capability assessment. Fisk et al. (2002) and Brunner et al. (2019) found significantly lower results on TMT in participants after TBI in comparison with the control group. Lundqvist, Alinder, and Ronnberg (2008) followed two groups of individuals with TBI or subarachnoid hemorrhage and their controls over a period of 10 years. They found significantly higher results on the The Trail Making Part B, in patients after TBI who drove again and those who did not. Hargrave, Nupp, and Erickson (2012) conducted a study to investigate the predictive utility of the Trail Making Test Part B and the Frontal Assessment Battery (Dubois et al., 2002) for on-road driving performance in 76 participants after stroke or TBI. The results showed that Scores on the Trail Making Test Part B and a cut-off score of 90 seconds correctly identified 77% of participants who failed on-road driving evaluations (Hargrave et al., 2012). Cullen and colleagues (2014) concluded that scores on the Trail Making Test Parts A and B were significantly better in participants who had returned to driving compared to those who had not done so. In a recent study, Crivelli et al. (2018) identified cognitive tests that best predict driving ability in subjects with mild dementia. Neuropsychological tests that correlated with all components of the Driving Assessment were the TMT–B, semantic verbal fluency (animals) and the FDS (Forgetfulness Detection Scale). In a sample of Parkinson's disease patients, Karagkiolidou et al. (2018) concluded that the combination of CDT (Clock drawing test), TMT A and TMT B explained 38% of the variance in headway distance under high traffic conditions in a rural driving environment.

The rate of re-integration of a driver who suffered mild to severe acquired brain injury (ABI) after a reassessment varies between 32% and 52% (Coleman et al., 2002; D'apolito et al., 2013; Formisano et al., 2005; Hawley, 2001; Novack et al., 2000; Novack et al., 2010; Pietrapiana et al., 2005; Rapport et al., 2008). Some studies show even higher rates where between 40% and 78% of ABI survivors regain their ability to drive (Lundqvist, 2001; Lundqvist et al., 2000). As it is generally one's own responsibility to apply for re-testing, many survivors continue to drive without a medical exam (Brouwer et al., 2002), even though people with acquired brain injury have higher risk of road accidents compared to healthy population (Korteling & Kapetein, 1996). Sadly, professionals in medical settings are often poorly informed about laws on license suspension and the necessity of re-testing for a driver's license after neurological disorders and cannot efficiently educate patients about driving restrictions (Classen et al., 2009; Hawley, 2001). Even a mild traumatic brain injury can have a significant impact on the fitness to drive. Schmidt and colleagues (2016) conducted a study to compare driving performance between individuals with and

without a concussion and to explore relationships between neuropsychological and driving performance. Poorer performance on symbol digit modalities test, Rey-Osterrieth Complex Figure, verbal memory, and motor speed tests were correlated with more frequent lane excursions in the concussed group, but not in the control group. They concluded that driving impairments may persist when individuals with a concussion have returned to driving.

In rehabilitation settings people with acquired brain injuries (ABI) are often eager to know whether they can drive again. Driving allows one to continue living and caring for self and others independently and is seen as one of the more challenging disabilities and primary worries in late rehabilitation stages (Rapport et al., 2008). Physical disabilities can be bridged by ergonomic changes recommended by a technical engineer based on a thorough medical report. However, when cognitive disabilities are present a complete neuropsychological assessment is required in order to discover specific adjustments one needs in order to return to traffic safely (Wolpe & Lehouckey, 2016). In Slovenia, the medical examinations of people with special needs, including people with TBI and stroke, are carried out in a Drivers' medical unit at the University Rehabilitation Institute Soča. A multidisciplinary team includes consultations with a physical medicine and rehabilitation specialist, a clinical psychologist, an engineer and a driving instructor. A thorough assessment of the patient's level of perceptual, physical and cognitive abilities is carried out. Driving is advised against for patients with TBI or stroke within six months from the onset of the disease or injury, and after that period a patient is referred for an overall assessment. On the basis of gathered diagnostic information about the patient, an estimate is given whether the person is capable of re-driving or not (Zupan & Marinček, 2013).

The combination of three assessment approaches tends to provide information that could potentially serve as a basis for the decision tree algorithm. The neuropsychological assessment gives us information about cognitive abilities of a patient in a certain environment. However, the results cannot be completely generalized to real-life conditions. Secondly, a driving simulator gives us the insight into operative and tactical decision making while driving but is performed in quiet laboratory settings. And thirdly, a practical driving assessment with a driving instructor gives us best ecological validity.

The objective of this study was to evaluate predictor variables of different assessment approaches (medical documentation, neuropsychological assessment, and Mediatester driving assessment) on the patient's ability to drive (passing the practical driving test with a qualified instructor). Results from various studies presented above confirm the use of TMT B as a good predictor of the ability to drive after neurological disorders. In light of that, we hypothesized that Comprehensive Trail-Making Test (CTMT) (Spreeen & Strauss, 1998, Reynolds, 2002), a measure which mimics the TMT-Part B alphanumeric alternation sequence, but adds an additional difficulty component of empty distractor circles will be the best predictor of the fitness to drive.

Method

Participants

The study participants were pooled from the database of the University Rehabilitation Institute Soča in Slovenia. They were included in the study based on the following criteria: traumatic brain injury, hypoxia, brain stroke, encephalitis, subjects who obtained their driver's license at least 1-year prior to the trauma, subjects with recovery time post trauma of at least 6 months. Patients with past psychiatric illness, alcohol or drug dependency, intellectual disability, aphasia, pregnancy, hemianopsia, or an inability to communicate in the national spoken and/or written language were excluded from the study.

The study included 63 participants (54 males, 9 females), between 20 and 80 years of age ($M = 44.4$; $SD = 16.7$). 45 participants were survivors of the TBI (from which 40 have no memories of the accident) and 18 survived ischemic strokes. Information about post-traumatic amnesia was available for 33 participants; 28 experienced it for less than 11 weeks and 5 participants showed signs of post-traumatic amnesia equal to or longer than 11 weeks.

Post injury period when included into testing varied; up to 20-month ($n = 29$), 20–40 months ($n = 17$), 40–60 months ($n = 4$), 60–80 months ($n = 6$), 80–100 months ($n = 2$), 100–120 months ($n = 2$). The longest post injury period at the time of the inclusion was 120 to 140 months for 3 people.

9% of all participants have had a driving license for less than 3 years prior to injury, 11% for less than 8 years and 79% for more than 8 years prior to injury.

26 participants who were evaluated post trauma reobtained their driving licences, 37 participants were not able to show the same driving skills as before the accident and did not regain driving licences ($n = 13$) or obtained driving licences with specific limitations ($n = 24$).

Measures

Assessment of driving abilities was carried out on Fiat's Mediatester, which is used for measuring psychophysical parameters required for safe driving such as power at braking and steering the steering-wheel, reaction times and correctness of reactions, visual field, and simulation of actual driving. The outcome variables in the study were simple reaction time (RTAV), visual reaction time (VRT), acoustic reaction time (ART), choice reaction test (CRT) and 18-light reaction test (18 LRT).

Simple reaction time (RTAV) is the reaction time measured from releasing the accelerator pedal (lever) to depressing the brake pedal (lever) as a light and acoustic signal appears, while visual reaction time (VRT) is the reaction time from the appearance of visual (light) signal to depressing the brake pedal. Acoustic reaction time (ART) is the reaction time from the appearance of the acoustic signal to pressing the brake pedal. In the Choice reaction test (CRT), there are two red and two green lights, which light up in a random order. The starting point is the foot on the accelerator pedal. In case of one green or two green and one red light, the driver has to hold the accelerator pedal, whereas for one red or two red and one green light the brake pedal should be pressed as quickly as possible. Correctness of reactions is measured. In each test, 20 combinations of lights are presented. The 18-light reaction test (18 LRT) measures total reaction times in which we analyze the thinking time and the time to perform the movement. There are 3 lights in a horizontal row at three different heights. The lights light up in random order. The participant has his foot on the accelerator pedal (lever) and must press the brake as soon as possible when the red light appears. The test comprises 18

measurements of reaction time, hence its name. The assessment was performed by a qualified mechanical engineer.

Debeljak et al. (2019) recently published a brief research report where they confirmed the validity and usefulness of the Fiat's Mediatester for research purposes.

Neuropsychological assessment consisted of the following domains and corresponding tests: mental processing speed (CTMT – Comprehensive Trail-Making Test [Spree & Strauss, 1998]), selective attention (d2 – Test of Attention (paper-pencil version) [Brickenkamp & Zillmer, 2002]), sustained attention (COG – Cognitron (computerized) [Schuhfried, 2005]), visual-spatial abilities (LVT – Visual Pursuit test (computerized) [Schuhfried, 2005]; VOT – Hooper Visual Organization Test [Hooper, 1983]), verbal learning and memory test (C4 – A – California Verbal Learning Test [Delis et al., 2000]), and executive functioning (TOL – Tower of London [Culbertson & Zilmer, 2005]).

The Comprehensive Trail Making Test (Reynolds, 2002) is a revised version of the original Trail Making Test (TMT) (Spree & Strauss, 1998). The task involves the immediate recognition of symbolic meanings, »scanning« by sequences, the flexibility to integrate numerical and word series, and the organization of all these activities within a time frame. The outcome variable in this study was the composite index (*t*-value).

The d2 test of attention assesses selective and sustained attention, the relationship between speed and accuracy coordination (mental concentration), and attentional control (Brickenkamp & Zillmer, 2002). The outcome variable was the concentration performance, which provides an index of the coordination of speed and accuracy of performance.

The Cognitron test is a computer-based assessment of attentional performance and concentration (Schuhfried, 2005). Abstract figures are presented on the screen, and the participant has to compare them to decide whether the two are the same. The outcome variable was *t*-value derived from all the correct answers.

The Visual Pursuit test (computerized) (LVT) (Schuhfried, 2005) is a computer-aided design of visual scanning, visual orientation and visual-perceptual abilities. The participant has to visually track simple visual stimuli within a relatively complex environment and has to remain focused while ignoring the distractors. The outcome variable was *t*-value derived from all the correct answers.

Hooper Visual Organization Test (Hooper, 1983) measures the ability to analyze and integrate visual stimuli and is sensitive to neurological impairment (Hooper, 1983). Participant identifies 30 objects represented in line drawings as puzzle pieces. The outcome variable was the sum of all correct answers on the test.

The California Verbal Learning Test (Delis et al., 2000) measures the strategy and process of learning and storing verbal information. The examiner reads sixteen words five times. The participant has to repeat all words, regardless of order, after each set of words is read. The outcome variable is the sum of all recalled words through all five learning trials.

Tower of London (TOL) (Culbertson & Zilmer, 2005) measures higher order problem-solving abilities. It was developed to identify impairments in the planning processes involved in generating a plan to accommodate novel demands and is a measure of the planning ability. The examiner uses one tower and a set of beads to display the desired goal and the examinee rearranges a second set of beads on a second tower to match the examiner's configuration. The outcome variable was the Total Move Score.

The assessments were performed by a qualified clinical psychologist.

The last part of assessment contained a test of practical driving with the driving instructor who was trained to work with people with special needs. The car was adapted, in accordance with the rules on equipment of vehicles in the driving school, with the possibility of breaking on the instructor's side. Practical driving with a driving instructor was held in a radius of 25 km and included all road infrastructure elements in the settlement and outside (including the motorway). After driving, the driving instructor completed the survey and evaluated: the ability to adapt speed to weather and traffic conditions, maneuverability (braking, rear view mirror), distance between vehicles, traffic behavior (consideration for other road users), compliance with traffic rules in road transport, driving planning and lateral position (depending on the line, circuits, intersections). The instructor evaluated each of these categories of driving behavior on a 5-point Likert scale (1 = *never*, 3 = *sometimes*, 5 = *always*) and gave an overall rating of the participants driving abilities (passed or failed the driving test or passed with restrictions).

Procedure

This study was approved by the Research Ethic Board at the Medical Faculty of the University of Ljubljana and in accordance with The World Medical Association (The Declaration of Helsinki).

Data was gathered at the Drivers medical unit at the University Rehabilitation Institute of the Republic of Slovenia from January 2016 to June 2017, following a protocol: (1) medical documentation and demographic data collection, (2) assessment of driving abilities with Mediatester driving assessment (3) neuropsychological assessment, and (4) passing the practical driving test with a qualified instructor.

Medical documentation records were screened for the social and demographic data, profession, Glasgow Coma Scale (GCS) assessment, post-traumatic amnesia, data and time post trauma. Semi-structured interview revealed the reasons for trying to regain driver's license and driving experiences in years.

Statistical Analysis

Data were analyzed using the SPSS software package (Version 21). For all the variables we considered, we first calculated the descriptive statistics and produced graphical representations of the distributions. Because of the small sample size and mostly abnormal distribution of variables (as calculated by Kolmogorov – Smirnov and Shapiro-Wilks test) we used non-parametric Wilcoxon-Mann-Whitney U test for calculating differences between two groups. In addition to these calculations, the measure of the size of the effect (r) is also included. It was calculated using the formula z/\sqrt{N} , as suggested by Field (2013, p. 550), whereas z -score represents statistic of a normal approximation test as calculated in SPSS software, and N is the number of total observations on which z is based. Connection of several predictive factor variables (i.e., results on different concentration questionnaires, reaction tests, etc.) with outcomes (i.e., the outcome of the driving test) were analyzed by binary logistic regression.

Connection of several predictive factor variables (i.e., results on different concentration questionnaires, reaction tests, etc.) with outcomes (i.e., the outcome of the driving test) were analyzed by binary logistic regression. The Bonferroni's correction for multiple comparisons was used for calculating statistical significance levels.

Results

Descriptive statistics of all variables are listed in Table 1 (see below).

Table 1
Descriptive statistics on different tests and demographic variables

		Result of a driving test	<i>N</i>	<i>M</i>	<i>Me</i>	<i>IQR</i>
Demographic variables	Age	passed the driving test	26	43.38	42.00	28.00
		did not pass the driving test or passed it with adjustments	37	45.19	46.00	29.00
	Education (in years)	passed the driving test	26	12.19	12.00	2.00
		did not pass the driving test or passed it with adjustments	37	11.36	12.00	1.00
	Amnesia (in weeks)	passed the driving test	15	5.18	1.50	4.00
		did not pass the driving test or passed it with adjustments	18	6.46	4.00	7.00
	Time from injury (in months)	passed the driving test	26	18.96	11.50	19.00
		did not pass the driving test or passed it with adjustments	37	44.03	28.00	15.00
	Coma duration (in weeks)	passed the driving test	18	1.34	0.95	3.00
		did not pass the driving test or passed it with adjustments	22	5.85	4.00	7.00
	<i>GCS</i>	passed the driving test	19	9.32	11.00	9.00
		did not pass the driving test or passed it with adjustments	21	4.57	3.00	2.00
Mediatester variables	RTAV (t-value)	passed the driving test	26	39.46	38.50	15.00
		did not pass the driving test or passed it with adjustments	37	28.62	31.00	14.00
	ART Total RT (in seconds)	passed the driving test	25	0.98	0.90	0.40
		did not pass the driving test or passed it with adjustments	37	1.65	0.96	0.67
	CRT – correct reactions – (M in seconds)	passed the driving test	26	1.01	0.96	0.34
		did not pass the driving test or passed it with adjustments	37	1.14	1.03	0.41
	18 LRT (in seconds)	passed the driving test	26	0.77	0.76	0.22
		Result of a driving test	<i>N</i>	<i>M</i>	<i>Me</i>	<i>IQR</i>

Neuropsychological assessment variables	VRT Total RT (in seconds)	did not pass the driving test or passed it with adjustments	37	0.93	0.88	0.37
		passed the driving test	26	0.83	0.84	0.30
		did not pass the driving test or passed it with adjustments	36	0.98	0.83	0.24
	TOL – Total Move Score	passed the driving test	26	37.12	32.50	38.00
		did not pass the driving test or passed it with adjustments	37	45.16	38.00	39.00
	CVLT (sum of all recalled words in all the trials)	passed the driving test	26	46.62	43.50	19.00
		did not pass the driving test or passed it with adjustments	37	38.46	40.00	15.00
	HOVT (sum)	passed the driving test	26	22.52	23.50	6.00
		did not pass the driving test or passed it with adjustments	37	20.27	21.00	9.00
	D2	passed the driving test	26	3.27	3.00	1.04
		did not pass the driving test or passed it with adjustments	37	2.19	2.00	1.00
	<i>CTMT (composite index – T)</i>	passed the driving test	26	31.19	33.50	2.00
		did not pass the driving test or passed it with adjustments	37	23.41	21.00	13.00
	COG (<i>t</i> -value)	passed the driving test	26	43.69	42.00	16.00
		did not pass the driving test or passed it with adjustments	37	38.51	36.00	9.91
	LVT (<i>t</i> -value)	passed the driving test	26	42.69	40.00	17.00
		did not pass the driving test or passed it with adjustments	37	35.27	32.00	16.00
Driving-related variables	Average of all the ratings from the instructor		63	4.33	4.76	0.20
	Driving experience (in years)		63	25.14	24.00	1.50

Note. The variables included in the final regression model are shown in italic.
N = number of participants; *M* = arithmetic mean; *Me* = median; *IQR* = interquartile range.

The relationship between several predictive factors variables (i.e., results on different concentration questionnaires, reaction tests, etc.) and the results (i.e., the outcome of the driving test) were analyzed with binary logistic regression. The results are listed below:

Table 2
Results of binary logistic regression with 13 predictors

Predictor	<i>b</i>	<i>SE</i>	Wald's <i>z</i>	<i>p</i>	RO	95 % confidence interval	
						lower	upper
Constant	116.79	186.90	0.39	.53			
GCS	1.79	2.26	0.62	.43	5.96	0.07	499.53
ART – Total Reaction Time (sec)	-4.31	6.23	0.48	.49	0.01	< 0.001	2684.77
LVT (t-value)	-1.56	2.28	0.47	.49	0.21	0.002	18.23
18 LRT (mean of the total reaction time in seconds)	-78.25	120.26	0.42	.52	<0.001	< 0.001	2*1068
D2 concentration measure	34.29	53.34	0.41	.52	8*1014	< 0.001	2*1060
TOL (total move score)	-0.31	0.49	0.39	.53	0.73	0.28	1.93
CRT (mean of correct reactions (sec))	-40.17	63.92	0.40	.53	<0.001	< 0.001	9*1036
VRT (total reaction time (sec))	50.10	80.42	0.39	.53	6*1021	< 0.001	2*1090
CTMT (composite index t-score)	-0.22	0.40	0.31	.58	0.80	0.37	1.75
COG (t-score)	-0.67	1.24	0.30	.59	0.51	0.05	5.78
CVLT (sum of words)	-0.38	0.78	0.24	.62	0.68	0.15	3.15
RTAV (t-score)	-0.42	0.87	0.23	.63	0.66	0.12	3.61
VOT (sum)	-0.85	2.14	0.16	.69	0.43	0.01	28.53
The likelihood ratio test	12. 37, $\chi^2 = 41.46$, $df = 13$, $p < .001$						
Nagelkerke R2	87.5 %						
Hosmer-Lemeshow test	$p = .72$						
Accuracy of classification	97.4 %						

Note. The predictors are listed from lower to higher statistical significance.

The results show that the chosen model is better than the null hypothesis. Our proposed model successfully statistically separates the predicted outcome category (0 = *did not pass the driving test*/passed the driving test, but with adjustments and 1 = *passed the driving test*) (area under the ROC curve > 0.80).

The value of Nagelkerke's pseudo-R² (analog to the proportion of explained variance in multiple linear regression) is high.

None of the individual predictors were statistically significant. In many predictors, the variability between the lower and upper limits of 95% of the confidence interval for the ratio is high. We can conclude that the presented model is inadequate for predicting our outcome variable (0 = *did not pass the driving test/ passed with restrictions* and 1 = *passed the driving test*). This can be due to the large number of predictors in the model in terms of the total number of participants in the analysis ($N = 39$) and on the other hand might also be due to the occurrence of multicollinearity between the predictor variables.

In light of that, we decided on a narrower selection of test predictors. Findings of several studies (e.g., Marshall et al., 2007) show that tests that measure a range of cognitive abilities have better predictive value for driving outcomes than measures assessing separate cognitive. Based on previous research showing that TMT B was a good predictor of the ability to drive after neurological disorders, we included the Comprehensive Trail-Making Test (CTMT) (Spreen & Strauss, 1998) in the second model. We added the 18 LRT that assesses executive functioning, psychomotor speed and spatial abilities and the GCS. GCS as an indicator of severity of injury, was included because we hypothesized that lower GCS would predict lower possibility of return to drive after brain injury.

Table 3
Logistic regression model

Predictor	<i>b</i>	<i>SE</i>	Wald's <i>z</i>	RO	95 % confidence interval	
					lower	upper
Constant	1.05	2.73	0.15			
18 LRT (mean of the total reaction time in seconds)	– 8.82*	3.85	5.25	0.00	0.00	0.23
CTMT (composite index t-score)	0.13*	0.06	4.46	1.14	1.01	1.29
GCS	0.37*	0.14	7.11	1.44	1.10	1.88
The likelihood ratio test	28.18, $\chi^2 = 27.73$, $df = 3$, $p < .001$					
Nagelkerke R ²	65.8 %					
Hosmer-Lemeshow test	$p = .14$					
Accuracy of classification	90.0 %					

Note. * $p < .05$.

From the results in Table 3 we can conclude that the proposed model was better than the null hypothesis (p value of the likelihood ratio test was under .005) and it does not statistically deviate from the data (Hosmer-Lemeshow test

is above .05). Via ROC analysis and inspection of sensitivity and specificity it was determined that predictors in the model predict patients being fit or unfit to drive rather well; AUC = 0.93 (95% CI [0.85–1.00], $p < .001$), the true positive rate (i.e., sensitivity) = .84, the true negative rate (i.e., specificity) = .95, precision = .94, and accuracy = .90.

The value of Nagelkerke's pseudo-R² (analogous to the proportion of the explained variance in multiple linear regression) is relatively high in comparison to other models that we inspected previously. The best predictors are: 18-light reaction test (18 LRT), Comprehensive Trail Making Test (CTMT) and Glasgow Coma Scale (GCS). Longer reaction times on 18 LRT likely predicts that patients will not pass the driving test or pass it with restrictions, while higher achievements on both other tests (CTMT and GCS) predict passing the driving test.

Table 4

Differences scores between groups (passed the driving test vs. did not pass the driving test or passed it with adjustments) on different tests and demographic variables

		<i>N</i>	<i>U</i>	<i>df</i>	<i>p</i>	<i>r</i>
Demographic variables	Age	63	461	61	.780	0.04
	Education (in years)	63	587	61	.119	0.20
	Amnesia (in weeks)	33	74	31	.027	0.39
	Time from injury (in months)	63	285	61	.006	0.35
	Coma duration (in weeks)	40	82	38	.001	0.50
	<i>GCS</i>	40	317	38	.001	0.51
Mediatester variables	RTAV (<i>t</i> -value)	63	729	61	< .001	0.44
	ART Total RT (in seconds)	62	386	60	.272	0.14
	CRT – correct reactions – (M in seconds)	63	361	61	.092	0.21
	<i>18 LRT (in seconds)</i>	63	315	61	.020	0.29
	VRT Total RT (in seconds)	62	404	60	.357	0.12
Neuropsychological assessment variables	TOL – Total Move Score	63	385	61	.180	0.17
	CVLT (sum of all recalled words in all the trials)	63	629	61	.039	0.26
	HOVT (sum)	63	599	61	.100	0.43
	D2	63	228	61	< .001	0.46
	<i>CTMT (composite index – T)</i>	63	743	61	.000	0.45
	COG (<i>t</i> -value)	63	637	61	.029	0.27
	LVT (<i>t</i> -value)	63	665	61	.009	0.33
Driving-related variables	Average of all the ratings from the instructor	47	458	45	< .001	0.58

Note. The results where $p < .05$ are shown in bold. The variables included in the final regression model are shown in italic (GCS, 18 LRT, CTMT).

N = number of participants; *U* = Wilcoxon-Mann-Whitney U statistic; *df* = degrees of freedom; *r* = size of effect measure.

We made two sets of group comparisons. In the first, we included the three predictors from the regression model (shown in *italic*). Those who passed the driving test with adjustments and those who did not pass compared to those who passed have on average a statistically significantly shorter reaction time (medium or large effect size) on the 18-light reaction test (18 LRT), a higher composite index on the Comprehensive Trail-Making Test and a higher score on the Glasgow Coma Scale (GSC). After using the Bonferroni's correction for multiple comparisons ($p = .5/3 = .17$), the 18-light reaction test (18 LRT) is slightly outside the margins of significance ($p = .20$), but technically no longer falls below the statistical significance level.

In the second group comparison, we included all other variables. Again, we used the Bonferroni's correction for multiple comparisons ($p = .5/16 = .003$). The results showed that those who passed the driving test with adjustments and those who did not pass compared to those who passed have on average a statistically significantly shorter coma duration time, a higher score on the Reaction Test for Audible and Visual Stimuli, d2 test of attention and a higher average rating from the driving instructor.

Discussion

Based on results of statistical analyses presented above, we conclude that the results of the neuropsychological testing, Mediatester driving assessment and medical documentation predict the ability to safely participate in road transport. Patients who pass a driving test with limitations and those who do not pass a driving test, compared to those who pass a driving test, have on average a statistically significantly (medium or large effect size) higher composite index on Comprehensive Trail-Making Test (CTMT) and a higher score on the Glasgow Coma scale (GCS). However, we have to be cautious with interpreting the Glasgow Coma results, as we had a heterogeneous group of TBI and stroke survivors. The results on the 18-light reaction test (18 LRT) were slightly outside the margins of significance, but show a trend that reaction time could also play a role in predicting the ability to drive after acquired brain injury. The model with these three predictors successfully classified 90.0 % of participants into the two groups passed vs. did not pass a driving test/passed the driving test with adjustments.

The TMT-B has been proven as a good predictor of the assessment of driving abilities in TBI (Cullen et al., 2014; Cyr et al., 2009; Fisk et al., 2002; Hargrave et al., 2012; Lundqvist et al., 2008; Novack et al., 2000), stroke (Hargrave et al., 2012; Alexandersen et al., 2009; Motta et al., 2014) and subarachnoid hemorrhage (Lundqvist et al., 2008) survivors. The groups with neurological condition described had significantly lower results on TMT-B in comparison with control groups (Brunner et al., 2019; Fisk et al., 2002; Lundqvist et al., 2008; Motta et al., 2014; Novack et al., 2000). In addition, the

researchers found higher results on the TMT–B in patients after TBI who drove again and those who did not (Cullen et al., 2014; Lundqvist et al., 2008).

The 18-light reaction test (18 LRT) on the Mediatester driving assessment and the Comprehensive Trail-Making Test (CTMT) measure multiple cognitive abilities. 18 LRT assesses executive functioning, psychomotor speed, and spatial abilities, while CTMT measures working memory, divided attention, selective attention, executive skills, and psychomotor speed (Reynolds, 2002). Those cognitive abilities form the basis for safe driving and efficient response behind the wheel. Poorer performance on the CTMT may indicate problems with filtering out irrelevant information behind the wheel and focusing on the things that demand our attention (selective attention), which is crucial in safe driving. Problems on the neuropsychological test CTMT could also indicate deficits with attending to multiple stimuli and conducting various tasks behind the wheel (divided attention). Slower mental processing of information could manifest itself as a longer reaction time, slower driving, and consequently slower decision-making (Van Zomeren and Brouwer, 1994). All this may constitute a major obstacle to the safe participation on the road.

Since the driving environment is a very complex situation that requires the mobilization of many cognitive abilities and skills, it appears logical that neuropsychological tests that assess multiple cognitive domains appear to have the best reproducibility in predicting fitness to drive (Marshall et al., 2007). One of the reasons why tests assessing a specific cognitive domain (e.g., simple reaction times) could not prove to be important predictors could be that they are too simple or cover only a small portion of abilities important for driving.

Impairments in other cognitive domains (e.g., language, memory) may negatively affect one's driving capacity, but the literature offers mixed findings regarding the contributions these make to safe driving (Bliokas et al., 2011; Devos et al., 2011; Marshall et al., 2007; Wolpe & Lehockey, 2016). The results of our study are in line with the conclusion of other authors that tests for measuring linguistic abilities and verbal memory showed less or no predictable power (Bliokas et al., 2011; Devos et al., 2011; Marshall et al., 2007). In this study, the measures assessing memory and language (CVLT) have not proved to be important predictors of the fitness to drive. Similar to our results, the tests that measure visual-spatial abilities alone (LVT, VOT) turned out to be poor predictors of driving performance when making a determination of an individual's driving fitness (Wood et al., 2009).

Limitations and Future Directions

Due to the lack of standardized questionnaires and neuropsychological tests in the Slovenian language, we resorted to the use of foreign normative data, which can reduce the possibility of generalizing our conclusions. The differences that we observed could thus be incorrectly attributed, as they could also arise due to time and national or cultural differences. In the current study we did not include a control group of participants without neurological disease/injuries, which would allow us to make more accurate conclusions about differences in mental states and cognitive abilities among patients and the general population.

The reason was the difficult accessibility and unwillingness to participate in the study with extensive neuropsychological testing which required more than an hour of assembly and problem solving. As a possible improvement we propose above all a larger, more representative sample.

Conclusions

The results of this study demonstrate that neuropsychological tests of multiple cognitive abilities, especially measures of processing speed and cognitive flexibility, have better predictive value for driving outcomes than measures assessing separate cognitive abilities. The combination of medical information, neuropsychological tests and Mediatester assessment data predicted the ability to drive assessed by a practical driving test for participants following a neurological disorder. Overall, these findings provide some direction for future development of clinical guidelines that are needed to treat patients after neurological disorders. We propose that future research should continue to focus on studies of multifactor assessment of driving abilities that show promising results and extend the findings to gather longitudinal data about the successfulness of the re-integration of the drivers after acquired brain injury to the traffic.

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Predviđanje faktora sposobnosti za vožnju nakon stečene povrede mozga na osnovu kombinovane neuropsihološke i Mediatester procene

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Cilj ove studije je bio da se oceni koliko dobro se na osnovu prediktorskih varijabli koje potiču iz različitih metoda procene (medicinska dokumentacija, neuropsihološka procena i Mediatester procena vožnje) mogu predvideti sposobnosti pacijenata da voze nakon traumatske povrede mozga ili moždanog udara (tj. da polože praktični test vožnje sa profesionalnim instruktorom). U istraživanju je učestvovalo 63 učesnika (54 muškaraca) starosti do 20 do 80 godina ($M = 44.4$; $SD = 16.7$). Većina pacijenata je imala neku traumatsku povredu mozga, a njih 18 je uključeno nakon ishemijskog moždanog udara. Pacijenti koji su položili test vožnje su imali značajno viši kompozitni skor na testu razumevanja pravljenja putanja (eng. Comprehensive Trail-Making Test) (srednja ili velika veličina efekta) u odnosu na one koji nisu položili test ili one koji su ga položili sa ograničenjima. Rezultati na testu reakcije na 18 svetala (eng. the 18-light reaction test; 18 LRT) ukazuju da reakciono vreme može takođe imati ulogu u predviđanju sposobnosti za vožnju. Na osnovu modela sa ova dva prediktora uz Glazgov koma skalu, 90% ispitanika je uspešno klasifikovano na one koji su položili vožnju i one koji nisu položili ili položili uz ograničenja. Rezultati ukazuju da su neuropsihološka i procena vožnje na osnovu kognitivnih sposobnosti bolji prediktori ponovnog sticanja sposobnosti za vožnju nakon traumatske povrede mozga nego pojedinačne kognitivne sposobnosti.

Ključne reči: neuropsihologija, neurorehabilitacija, vožnja, procena, povreda mozga.

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