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Cognitive Performance and Psychological Well-being in Chronic Traumatic Spinal Cord Injury: Comparison of Cervical SCI Group versus Orthopedic Injury Group

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ABSTRACT

The purpose of this study was to assess cognitive performance and psychological well-being in traumatic chronic cervical spinal cord injury (SCI). The results of a SCI group (n = 29) and an orthopedical injury (OI) group (n = 40) were compared. Participants were administered self -report measures of pain, post-traumatic and depressive symptoms as well as a comprehensive motor-free neuropsychological assessment battery. After controlling for demographic and psychological factors, group was a significant independent explanatory variable of cognitive performance in two neuropsychological measures (Categorical word fluency and WAIS-III Picture completion) with the SCI group performing worse than the OI group. Pain was a significant independent explanatory variable of performance in PASAT. In most of the evaluated neuropsychological measures, education years was a significant predictor of performance and had a positive relationship with neuropsychological test performance. In an individual level 24 % of the SCI participants met the criteria for cognitive impairment. SCI group reported more pain and more post-traumatic symptoms than OI group. In conclusion, cognitive impairment is a salient factor to consider in chronic cervical traumatic SCI, but most of the population seem to function cognitively within normal limits. Educational level is important to consider in neuropsychological assessment to avoid false positive evaluations for cognitive impairment. Pain management is of essence to support cognitive functioning in SCI.

Keywords:

spinal cord injury, tetraplegia, cognitive impairment, psychological well-being

INTRODUCTION

Traumatic spinal cord injury (SCI) is an impairment or loss of motor and/or sensory function due to the neural elements within the spinal canal caused by an external force (Kirshblum et al., 2011). Tetraplegia refers to lesions in the cervical segment of the spinal cord that result in the impairment of function in all four limbs, trunk and pelvic organs (Kirschblum et al., 2011). The extent of the damage to the spinal cord determines whether the injury is complete (no movement or feeling below the level of the injury) or incomplete (some degree of feeling or movement below the level of the injury). In traumatic SCI, impairment of voluntary control of motor and sensory functions below the level of injury affects somatic and autonomic nervous control of the blood vessels, respiratory tract, sweat glands, bowel, urinary bladder and sexual organs (Krassioukov et al., 2012). These impairments have various clinical consequences: the decrease in ability to walk or move, respiratory failure and complications, sympathetic cardiovascular dysfunction, disturbances of thermoregulation, neurogenic bladder or bowel dysfunction, sexual dysfunction, spasticity and chronic pain (e.g. Widerström-Noga, Felipe-Cuervo, Broton, Duncan & Yezierski, 1999). The multiple physiological problems after traumatic SCI are usually lifelong and have a major impact on functioning and quality of life (Dijkers, 1997; Burke, Lennon & Fullen, 2018).

Understandably traumatic SCI induces severe psychological stress that can lead to psychological difficulties. People with SCI have increased risks of developing major depression disorder (MDD), post-traumatic stress disorder (PTSD) or other negative psychological consequences during the rehabilitation phase or after returning to live in the community (Craig, Tran & Middleton, 2009). The prevalence of depression after SCI is substantially greater than that in the general medical population; the mean prevalence estimate of depression diagnosis after SCI is 22.2 % (Williams & Murray, 2015). Elevated levels of depressive mood ranges between 11 % and 60 % in people with SCI living in the community (Craig et al., 2009). It is suggested that the prevalence of PTSD after spinal cord injury ranges from 10 % to 40 % (Kennedy & Duff, 2001). People with paraplegia seem to suffer more PTSD symptoms than people with tetraplegia (Radnitz et al., 1998). Other risk factors for PTSD following SCI are e.g. symptoms of anxiety, female gender and negative attitudes towards emotional expression (Quale, Schanke, Frøslie, & Røise, 2009).

Research typically focuses on physical consequences and rehabilitation of motor functions in SCI. However, cognitive deficits are common. Cognitive deficits are reported up to 60 % in individuals with SCI (Sachdeva, Gao, Chan & Krassioukov, 2018). A person with SCI has a 13-fold risk to develop cognitive symptoms compared to healthy controls (Craig, Guest, Tran & Middleton, 2017). Cognitive deficits in SCI seem to be generally diffuse in nature and affect various domains of cognitive functioning, typically attention and concentration, processing speed, new learning and memory and executive functioning (Chiaravalloti, Weber, Wylie, Dyson-Hudson & Wecht, 2020; Davidoff, Roth & Richards, 1992; Dowler et al., 1995;

Dowler et al., 1997; Jedege et al., 2010; Roth et al., 1989). Previous research has tried to identify distinct profiles of cognitive functioning and characteristics of cognitive impairment in spinal cord injury (Dowler et al., 1997; Li, Huo & Song, 2021). According to Molina and colleagues (2018) cognitive dysfunctions in individuals with SCI are present in the subacute stage and worsen over time. Although the research literature on cognitive functioning in SCI is fast growing, there is still much to learn about cognitive functioning and the specific etiology of cognitive deficits in SCI. Factors related to cognitive performance in this population are many and complex.

There is a very limited number of studies researching traumatic chronic tetraplegic patients with a comprehensive neuropsychological test battery and comparing cognitive performance with another injury group. To my knowledge, there is only one study that compare the performance of chronic SCI patients with other injury group that uses comprehensive neuropsychological test battery (Zec et al., 2001). Sachdeva and colleagues (2018) identified in their systematic review fifteen studies that examine cognitive performance in chronic SCI participants compared to able-bodied controls. Only four studies used a more comprehensive neuropsychological test battery to evaluate cognitive performance. The other eleven studies used single tests, experimental tasks or questionnaires. Three of the four studies found group-level differences in cognitive performance with SCI group performing worse. Of these four studies (which use a comprehensive neuropsychological battery) only one study compared the cognitive performance of chronic SCI patients to another injury group (traumatic brain injury, TBI) (Zec et al., 2001). The TBI group performed cognitively worse than the SCI group. The SCI group performance did not differ from healthy controls other than in WAIS performance IQ. In the research article the authors did not clarify the assessment procedure of SCI participants on performance tests, since some of the subtests require motor functioning of the hands.

The purpose of this study was to assess cognitive performance in traumatic chronic cervical spinal cord injury with a comprehensive motor-free neuropsychological test battery and compare the results with the performance of other trauma group (orthopedical injury group, OI). We also examined the extent of cognitive deficits in SCI participants in an individual level. Furthermore, we were interested in psychological well-being of SCI group compared to OI group.

METHODS

Study Framework and Statement of Ethics

This study is part of the Spinal Cord Injury Series of Tampere -Retroprospective Study. The study aimed to examine SCI from a multidisciplinary perspective, in a case-control setting, to enhance the clinical assessment and treatment of this specific patient group. The ethics approval for the study was obtained from the Ethical Committee of Pirkanmaa Hospital District, Finland. A written informed consent was obtained from each participant. We certify that all

applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research.

Participants

All consecutive patients with a chronic traumatic cervical spine injury (n=88) who were admitted to either the ward or an outpatient clinic in Tampere University Hospital between 1989 and 2010 were contacted for participation in the study in 2011. The inclusion criteria were as follows: i) age over 18 years, ii) resident of the hospital district, iii) clinically significant neurological findings due to a traumatic cervical spinal cord injury after 24 hours of monitoring in the hospital and/or iv) time since injury greater than one year. The exclusion criteria were as follows: i) known neurological illness other than spinal cord injury, ii) respiratory arrest, iii) contraindications to MRI and/or iv) refusal to participate in the study. The main reason for exclusion was refusal to participate in the study (n=17). Neuropsychological assessments were conducted to 38 participants with cervical SCI. From the 38 neuropsychologically assessed SCI participants two were excluded because of severe psychiatric disorder, five because of significant not trauma related findings on MRI (moderate/severe microangiopathy or infarct) and another two because of age over 70 years. The final SCI group consisted of 29 participants.

The control group consisted of 40 neurologically intact orthopedically injured patients. The controls were recruited from consecutive patients with ankle trauma from the Emergency Department of Tampere University Hospital. A total of 609 patients with ankle injury were screened for participation. The inclusion criteria were as follows: i) age 18-60 years, ii) being a resident of the university hospital district and iii) ankle trauma. The exclusion criteria were as follows: i) neurological problems, ii) psychiatric problems, iii) history of traumatic brain injury, iv) former neurosurgical procedure, v) problems with hearing or vision, vi) first language other than Finnish, vii) contraindications to MRI and iix) refusal to participate.

Clinical assessment and neuroimaging

All participants with SCI were examined at an outpatient clinic in Tampere University Hospital. A clinical assessment of the participants was performed by a neurologist (E.K.). The etiology of the spinal cord injury was classified using the International SCI Core Data Set (Devivo et al., 2006). The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) was used to evaluate and classify the neurological consequence of spinal cord injury (Waring et al., 2010). The level of disability was assessed using the motor subscale of the Functional Independence Measure (FIM) (Maynard et al., 1997). The medical condition of the subjects was assessed according to the International Classification of Diseases and Related Health Problems 10th revision (ICD -10) (Ashley, 1990). Information on the current medication at the time of examination was classified into 17 subgroups according to the Finnish Commercial Drug Catalog

(Pharma Fennica), which was categorized based on the World Health Organization's Anatomical Therapeutic Chemical (ATC) Classification System codes.

The MRI examinations of the brain and spinal cord were performed using a 3T MRI scanner (Siemens Trio, Siemens Medical Solutions, Erlangen, Germany). The MRI protocol of the brain included sagittal T1-weighted 3-dimensional infrared-prepared gradient echo, axial T2 turbo spin echo, conventional axial and high-resolution sagittal FLAIR (fluid-attenuated inversion recovery), axial T2*, axial SWI (susceptibility weighted imaging), and DWI (diffusion weighted imaging) series. Interpretation of the imaging findings on the conventional MRI scans was performed by a neuroradiologist (A.B.).

Outcome measures

An extensive motor-free neuropsychological examination suitable for participants with tetraplegia (Hill-Briggs, Dial, Morere & Joyce, 2007) was conducted for each participant by the same psychologist (SR). The selected tests are well known and widely used in clinical practice. The neuropsychological examination of the orthopedical group was conducted at 1 month after the injury.

Verbal memory was evaluated using The Rey Auditory Verbal Learning Test (RAVLT; total number of words recalled in trials 1-5, recall after interference, and recognition after 30 minutes) (Lezak, Howieson, Loring & Fischer, 2004) and Logical Memory (immediate and delayed recall) from Weschler Memory Scale – Third Edition (WMS-III) (Wechsler, 2005b). Attention and executive functions were evaluated using The Stroop Test (Golden version, number of items completed in color-word interference trial) (Lezak et al., 2004), The Paced Auditory Serial Addition Test (PASAT; the number of correct answers in one series of 61 digits with the interstimulus time of three seconds) (Lezak et al., 2004), the phonemic (P/A/S) and semantic (animals) verbal fluency (number of words in one minute) (Strauss, Sherman & Spreen, 2006) and digit span of Wechsler Adult Intelligence Scale III (WAIS-III) (Wechsler, 2005a). Verbal intelligence was evaluated using WAIS-III's information and similarities (Wechsler, 2005a). Visual intelligence was evaluated using WAIS-III's matrix reasoning and picture completion (Wechsler, 2005a). Cognitive impairment was defined using published Finnish (WAIS-III (Wechsler, 2005a), WMS-III (Wechsler, 2005b), PASAT (Rosti, Hämäläinen, Koivisto & Hokkanen, 2007) and international normative data (Mitrushina, Boone, Razani & D'Elia, 2005). The participant was defined as having cognitive impairment if four or more of the fourteen cognitive test variables were at least one standard deviation below average. The criterion is based on studies examining the base rates of low scores in healthy adults when multiple scores are considered simultaneously (Binder, Iverson & Brooks, 2009; Brooks, Iverson, Feldman & Holdnack, 2009). Iverson and colleagues (2012) found that it is common for adults of average intelligence to have 20-30% of their test scores ≤ 1 SD from the mean, and it is common for adults with above average intelligence to have approximately 15 % of their test scores in this range.

Depressive symptoms were assessed with the Beck Depression Inventory – Second Edition (BDI-II) (Beck, Steer & Brown, 1996). BDI-II is a self-report questionnaire in which the total score ranges from 0 to 63. A total score of > 13 is considered indicative of depression (score 14-19 mild depression; score 20-28 moderate depression; score 29-63 severe depression).

Symptoms of posttraumatic stress disorder (PTSD) were assessed with PTSD-Checklist-Civilian Version (PCL-C) (Weathers, Litz, Herman, Huska & Keane, 1993). PCL-C is a reliable and valid scale to assess PTSD symptoms in civilians (Ruggiero, Ben, Scotti & Rabalais, 2003; Wilkins, Lang & Norman, 2011). The possible scores of the scale range from 17 to 85. The participants were defined as having probable PTSD if the total score of the scale was greater than 50 or the criteria for PTSD in DSM-IV (Bell, 1994) was fulfilled, and possible PTSD if the total score was greater than 35.

Pain was evaluated by the pain subscale of the Ruff Neurobehavioral Inventory (RNBI) (Ruff & Hibbard, 2003). The pain subscale is comprised of six items rated on a 4-poins scale (1-4), and the total score ranges from 6 to 24.

The Alcohol Use Identification Test (AUDIT) (Babor, Higgins-Biddle, Saunders & Monteiro, 1992) was used to detect alcohol problems. The AUDIT is widely used brief screening test to identify persons who have risky drinking, or alcohol dependence. The AUDIT consists of 10 questions, each which has a set of responses to choose from. A total score of 8 points is considered indicative of harmful or hazardous drinking (Reinert & Allen, 2007).

Data Analyses

Statistical analyses were conducted using SPSS for Windows version 25.0 and 27.0 with the partial supervision and help of a statistician (M.H.). Group differences were assessed using chi-square analyses for categorical variables (e.g. gender). Fishers Exact test statistics were interpreted when cell sizes were less than five. Continuous variables were tested with Mann Whitney U tests or t-tests. Nonparametric analyses (Mann Whitney U test) were conducted for the variables that were not normally distributed. This was done to describe and examine the characteristics of the SCI group in reference to orthopedic injury group and examine whether the groups differ in pain, mental health (depression or PTSD symptoms) and cognitive performance. Cohen d values were used to illustrate clinical significance. The linear regression analysis was conducted to determine independent predictors of variance in cognitive test performance. The six neuropsychological test variables with group differences were included in the regression model. The three demographic variables (age, gender, and education), group (SCI/ OI) and two self-report variables (PTSD and pain) were entered into to the regression analysis. Residuals of the regression analysis were found to be normally distributed and therefore the models were considered reliable. The statistical significance level was set to .05 for all the analyses.

RESULTS

Demographic and Clinical Characteristics

Clinical characteristics of the 29 SCI and 40 OI participants are shown in Table 1. A significant difference between the SCI and OI group was found in gender, age and post-injury work status. The groups did not differ in education years. There were more people using alcohol over at-risk limits in SCI group (37.9%) than in the OI group (15 %). Of the participants with SCI, four did not complete MR imaging. In the SCI group 20/25 (80 %) had findings on MR image (punctate white matter hyperintensities excluded) and 15/25 participants (60 %) had trauma related findings. Table 2 presents the MRI findings of the brain in SCI participants (n = 25). In addition to the findings listed in Table 2, there were findings of more localized atrophy changes and punctate white matter hyperintensities in SCI group. None of the OI subjects had significant structural abnormalities on conventional MRI scans. Of the participants with SCI, 17 (58.6%) used medication effecting the central nervous system.

Mood, PTSD, pain

The SCI group reported more pain and post-traumatic stress symptoms (PTSS) than OI group (see Table 1.) 24.1% of the SCI group and 12.5 % of the OI group were defined as having possible PTSD. 10.3 % of the SCI group and 2.5 % of the OI group were defined as having probable PTSD. These differences in the occurrence of possible or probable PTSD between groups did not reach statistical significance. Also, the SCI and OI groups did not significantly differ on depression symptoms. There was a significant positive correlation between pain and PTSS ($r_s = 0.55$, $N = 68$, $p < 0.001$, two-tailed), and pain and depression symptoms ($r_s = 0.58$, $N = 67$, $p < 0.001$, two-tailed). Also, significant positive correlation was found between PTSS and depression symptoms ($r_s = 0.75$, $N = 68$, $p < 0.001$, two-tailed).

Cognition

There were more participants with SCI (7/29, 24.1 %) meeting the criteria for cognitive impairment compared to OI participants (3/40, 7.5 %). Fisher's exact test was used to determine if there was a significant association between group and cognitive impairment. There was a trend towards statistically significant association between group and cognitive impairment (one-tailed $p = 0.06$). At the group level participants with SCI performed significantly worse than control group in four areas of cognition and in six of the neuropsychological measures: executive function (COWAT animal, Stroop color-word, PASAT), visual reasoning (WAIS-III picture completion), verbal reasoning (WAIS-III Similarities) and memory (RAVLT total recall) (see Table 3). Linear regression analysis was done to examine the predictors of variance in test performance in aforementioned six neuropsychological measures (See appendix Table a1).

COWAT animals

A significant model emerged: $F(6,61) = 4.72$, $p < .001$. The model explains 25 %

Table 1. Characteristics of participants with chronic spinal cord injury (SCI) and orthopedic controls (ankle injury).

Descriptive variables	**SCI** (n = 29)	**Controls** (n = 40)	**p-value**	**Cohen's d**
Demographics				
Gender Male: n (%)	24 (82.8)	20 (50.0)	**0.006**	NA
Age (years): Mean (SD)	54.7 (13.8)	40.1 (12.2)	**< 0.001**	1.24
Education (years): Mean (SD)	12.4 (4.0)	14.1 (2.8)	0.055	-0.51
Work status: n (%)			**<0.001**	NA
Full-time work	4 (13.8)	29 (72.5)		
Part-time work	0 (0.0)	2 (5.0)		
Studying	0 (0.0)	4 (10.0)		
Part-time retirement	1 (3.4)	0 (0.0)		
Full-time retirement	24 (82.8)	1 (2.5)		
Unemployed	0 (0.0)	3 (7.5)		
Missing data	0 (0.0)	1 (2.5)		
Injury-related				
Findings on MRI: n (%)	20 (80.0)	0 (0.0)	**<0.001**	NA
Trauma-related fidings on MRI: n (%)	15 (60.0)	0 (0.0)		
missing data: n (%)	4 (13.8)	0 (0.0)		
CNS medication: n (%)	17 (58.6)	0 (0.0)	**<0.001**	NA
Time since injury (years): Mean (SD)	12.8 (12.3)			
Minimum (years)	1.1			
Maximum (years)	43.0			
Injury etiology: n (%)				
Sport	6 (20.7)			
Transport (car/bike/pedestrian)	8 (27.6)			
Fall	15 (51.7)			
ASIA impairment scale (AIS): n (%)				
AIS A	8 (27.6)			
AIS B	1 (3.4)			
AIS C	4 (13.8)			
AIS D	15 (51.7)			
AIS E	1 (3.4)			
ISNCSCI single neurological level				
C1	2 (6.9)			
C2	2 (6.9)			
C3	3 (10.3)			
C4	11(37.9)			
C5	5 (17.2)			
C6	1 (3.4)			
C7	1 (3.4)			
C8	2 (6.9)			
T11	1 (3.4)			
FIM physical subscore: Mean (SD)	65.4 (28.0)			
Self-report measures				
Depressive symptoms (BDI-II): Mean (SD)	6.7 (5.3)	5.1 (5.4)	0.094	0.41
≥ 14 : n (%)	5 (17.2)	4 (13.8)	0.481	NA

Table 1. *Continued*

Descriptive variables	**SCI** (n = 29)	**Controls** (n = 40)	**p-value**	**Cohen's d**
PTSD Symptoms (PCL-C): Mean (SD)	30.3 (12.0)	24.4 (7.4)	**0.027**	0.55
Possible PTSD > 35: n (%)	7 (24.1)	5 (12.5)	0.335	NA
Probable PTSD > 50	3 (10.3)	1 (2.5)	0.070	NA
Pain subscale (RNBIPn): Mean (SD)	11.7 (11.0)	8.2 (8.0)	**<0.001**	0.90
Alcohol consumption (AUDIT): Mean (SD)	6.5 (5.1)	4.8 (2.9)	0.319	0.24
≥ 8: n (%)	11 (37.9)	6 (15.0)	**0.046**	NA
≥10	8 (27.6)	4 (10.0)	0.105	NA
≥14	3 (10.3)	0 (0.0)	0.070	NA
range	0-18	0-11		

NA = Not available; CNS = central nervous system
The proportions were compared with Fishers exact test and continous variables were tested with Mann Whitney- or t-test.

Table 2. The main MRI findings of the brain in SCI participants (n = 25).

Finding		**n**
Microangiopathy (mild)		3
Lacunar ischemic lesions		1
DAI-type microhemorrhage		10
	n = 1	8
	n = 2-5	2
Post-traumatic lesion		6
	diameter < 1cm	3
	diameter 1-2 cm	3
Atrophy		6
	mild global	5
	moderate global	1

MRI, magnetic resonance imaging; DAI, diffuse axonal injury

of the variance in the COWATanimal test performance (adjusted R2 = 0.250). Education years was a significant predictor with a positive relationship to COWAT animal performance. Group was a significant predictor with a negative relationship to COWAT animal performance.

RAVLT total recall

A significant model emerged: F (6,61) = 9.42, p <.001. The model explains 43 % of the variance in the RAVLT total recall test performance (adjusted R2 = 0.430). Education years was a significant predictor with a positive relationship to RAVLT total recall performance. Gender and age was a significant predictor with a negative relationship to RAVLT total recall performance.

Table 3. Comparison of neuropsychological variables (raw scores) of participants with SCI and OI controls.

Neuropsychological Test	SCI (n = 29)	Controls (n = 40)	p-value	Cohen´s d
	M ± SD (Md; range)	M ± SD (Md; range)		
COWAT animal	21.9 ± 5.2 (21.0; 12-34)	27.5 ± 6.0 (27.0; 16-41)	**< 0.001**	0.99
COWAT p/a/s	42.5 ± 14.2 (43.0; 18-76)	47.8 ± 14.3 (49.0; 26-86)	0.133	0.37
Stroop Color-Word	35.1 ± 8.8 (37.0; 15-57)	44.9 ± 10.1 (45.0; 29-76)	**0.000**	1.06
PASAT	41.7 ± 13.1 (44.0; 15-60)	48.6 ± 10.0 (52.0; 27-60)	**0.023**	0.57
WAIS-III Digit Span	14.7 ± 3.2 (15.0; 9-22)	16.6 ± 3.5 (16.0; 11-27)	0.052	0.53
WAIS-III Information	19.8 ± 3,5 (21.0; 11-24)	19.7 ± 3.4 (20.0; 11-25)	0.719	0.09
WAIS-III Similarities	23.1 ± 4.6 (23.0; 11-33)	25.2 ± 4.1 (25.0; 15-32)	**0.048**	0.49
WAIS-III Matrix Reasoning	18.0 ± 4.5 (17.0; 10-25)	20.0 ± 3.5 (21.0; 9-25)	0.072	0.44
WAIS-III Picture Completion	18.2 ± 3.8 (19.0; 8-23)	21.6 ± 2.4 (22.0; 15-29)	**< 0.001**	1.14
RAVLT total recall	50.2 ± 9.7 (50.0; 31-75)	56.7 ± 8.3 (56.5; 38-70)	**0.004**	0.73
RAVLT post-interference recall	10.6 ± 2.8 (11.0; 5-15)	11.9 ± 2.6 (12.0; 4-15)	0.056	0.47
RAVLT recognition	13.5 ± 1.8 (14.0; 9-15)	14.0 ± 1.7 (15.0; 7-15)	0.056	0.44
WMS-III Logical Memory 1	41.9 ± 9.4 (40.0; 21-60)	45.1 ± 9.2 (45.0; 24-62)	0.159	0.35
WMS-III Logical Memory 2	26.7 ± 7.6 (26.0; 11-38)	30.3 ± 7.3 (31.0; 15-43)	0.057	0.48

The comparisons were conducted using Mann Whitney- or independent samples t-test.

WAIS-III Picture Completion

A significant model emerged: F (6,61) = 4.3, p <.001. The model explains 23 % of the variance in the Picture completion performance (adjusted R2 = 0.228). Group was a significant predictor with a negative relationship to Picture completion performance.

WAIS-III Similarities

A significant model emerged: F (6,61) = 2.43, p <.001. The model explains 11 % of the variance in the Similarities test performance (adjusted R2 = 0.113). Education years was a significant predictor with a positive relationship to Similarities performance.

PASAT

A significant model emerged: F (6,61) = 7.83, p <.001. The model explains 38 % of thevariance in the PASAT test performance (adjusted R2 = 0.379). Pain and age weresignificant predictors with a negative relationship to PASAT performance.

Stroop total

A significant model emerged: F (6,61) = 7.92, p <.001. The model explains 38 % of thevariance in the Stroop color-word test performance (adjusted R2 = 0.383). Education years was a significant predictor with a positive relationship to Stroop color-word performance. Age was a significant predictor with a

negative relationship to Stroop color-word performance.

In summary, after controlling for gender, age, education years, pain and post-trauma symptoms, the group was a significant independent predictor of cognitive performance in two neuropsychological measures: Cate-gorical word fluency and WAIS-III Picture completion.

The SCI group was divided in two subgroups based on whether they were using central nervous system medication and whether they had findings in MRI imaging. Total of 17(58.6 %) participants in the SCI group used some CNS medication, while 12 did not. There were no significant differences in cognitive performance between the medication or no medication SCI subgroups (data not shown).Total of 20/25 (80 %) in the SCI group had findings in MRI imaging while 5/25 did not, and 4/29 (14 %) did not complete MRI imaging for different reasons. There were no significant differences in cognitive performance between the SCI subgroups with or without MRI findings (data not shown).

DISCUSSION

This study investigated cognitive performance and psychological well-being of chronic cervical TSCI compared to other injury group (OI). A comprehensive neuropsychological motor-free assessment battery was used. Results indicated a small difference in cognitive performance between the groups when demo-graphics and psychological factors were controlled. In an individual level 24 % of the SCI participants met the criteria for cognitive impairment.

The SCI group performed worse than IO group in six neuropsychological tests measuring executive functioning, reasoning and memory. The findings are in line with the growing research literature reporting cognitive impairment in individuals with SCI (Sachdeva et al., 2018). After controlling for demographics and psychological factors, however, group level difference was found in measures of verbal fluency and visual reasoning only (2 out of 14 measures). There are other studies reporting group level verbal fluency deficits in SCI participants (e.g. Chiaravalloti et al., 2020). Visual reasoning is not commonly reported to be impaired in SCI.

In this study other factors explained cognitive performance more frequently than the group. Significant other explanatory variables of cognitive performance in above mentioned tests were education years (in 4/6 measures), age (3/6), gender (1/6) and pain (1/6). In most of the evaluated neuropsychological measures, edu-cation years was a significant explanatory factor and had a positive relationship with neuropsychological test performance. The effect of education and age on neuro-psychological performance is well-known in the clinical field (Mitrushina et al., 2005). This is an important factor to consider in clinical practice with SCI patients and in research. It seems that in the research literature a common significant difference between chronic SCI and an able-bodied control group is education, with SCI participants having less education in a group level (Chiaravalloti et al., 2020; Molina et al., 2017). Pain is associated with impaired cognitive functioning (Moriarty, McGuire, & Finn,

2011). Although there were no significant differences in PASAT performance between the SCI and the OI group, pain was a significant independent explanatory factor of cognitive performance in PASAT. This finding is in line with a recent SCI study (Carlozzi et al., 2021) that also found that greater pain intensity was associated with lower PASAT scores in SCI. In our study the SCI group reported more pain than the OI group. According to a recent review article and meta-analysis, the pooled prevalence of overall chronic pain was 68% (95% CI 63% to 73%) in chronic SCI (Hunt et al., 2021).

Although the SCI group reported more PTSS than the OI group, the variable did not explain the variance on any of the six neuropsychological tests. Depressive symptoms, PSS and pain were positively associated with each other. E.g. Roth et colleagues (2008) indicated that symptoms of depression were significantly related to more severe pain, disability and PTSD symptoms in individuals with physical injury. They suggested that pain rehabilitation programs should include directed interventions for PTSD symptoms among individuals with chronic pain secondary to physical injury. In SCI rehabilitation it is of essence to target interventions on PSS and depressive symptoms to facilitate living with chronic pain.

Many of the common medications that are prescribed for individuals with SCI, may have a negative impact on cognitive performance. Central nervous system medication was used by 58.6 % of the SCI group. There were no differences in cognitive performance between SCI participants with or without medication. Also, Carlozzi and colleagues (2021) findings did not support a strong relationship between medication use and cognition in SCI. It should be noted that the subgroup sizes in this study were small for representative statistical analyses.

According to research literature, traumatic brain injury (TBI) is a likely injury in TSCI population (Davidoff, 1988, Macciocchi, Seel, Thompson, Byams & Bowman, 2008). In the study we had an effort to differentiate SCI individuals with possible TBI based on medical documents. Almost 40 % on the SCI individuals were injured over 10 years ago, the longest time since injury being 43 years. Hence medical records were not a reliable source to determine the prevalence of TBI in our SCI group. Fortunately, we had the opportunity to brain imaging in the study. To my knowledge there are no previous chronic SCI studies that have used a comprehensive neuropsychological battery, other trauma group as a control group, and MR-imaging to evaluate the participants individual clinical brain condition. In this study, 80 % of the SCI group had findings in brain MRI and 60 % had brain trauma-related findings (diffuse axonal injury type microhemorrhage and post-traumatic lesions). Hence, it seems that the prevalence of brain abnormalities is high in TSCI population. We compared the cognitive performance of the SCI group with brain MRI findings to SCI group with no MRI findings; there were no differences in cognitive performance between the two subgroups. Again, the SCI subgroup sizes were small for reliable statistical analyses.

Sleep apnea is associated with cognitivie deficits is non-SCI individuals (Bucks, Olaithe & Eastwood, 2013; Gagnon et al., 2014). The incidence of sleep disordered breathing (SDB) is high in SCI (Sankari, Bascom, Oomman & Badr, 2014; Chiodo, Sitrin & Bauman, 2016). Most SCI individuals have symptomatic SDB and poor sleep (Sankari et al., 2014). According to Chiodo and colleagues (2016) in their systematic review, SDB is particularly common in motor complete persons with tetraplegia (60 %) and central apnea is more common in tetraplegia than in paraplegia. In this study, SDB was not controlled for. But Rimpilä and colleagues (2012) conducted a SDB-study after spinal cord injury and used participants from the Spinal Cord Injury Series of Tampere – Retroprospective study (n = 25). They concluded that sleep apnea was a common finding (15/25 patients: 7 severe, 9 mild to moderate). So, it is likely that the incidence of SDB is also high is our SCI group, although the participants in Rimpilä and colleagues (2012) study may be at least partly different individuals than on this study.

This study has limitations. First, the final sample size of the study was small, and the SCI group was older and male-weighted compared to the OI group. Although, the age and gender difference between the groups was addressed with statistical methods. The range of the assessment time since the injury in SCI group was very wide (1-43 years). Second, cardiovascular dysfunction was not controlled for. Blood pressure dysregulation is a common symptom in SCI. Individuals with high cord injury are prone to bradycardia, hypotension and orthostatic hypotension. There is growing evidence that these conditions in able-bodied individuals results in cerebrovascular health problems leading to vascular cognitive impairment (VCI) (Sachdeva, Nightingale & Krassioukov, 2019). There is evidence suggesting that chronic hypotension in persons with SCI is associated with cognitive deficits (Jedege et al., 2010). It is known that impaired neurovascular coupling (NVC; i.e., cerebral blood flow responses to neurologic demand), secondary to low blood pressure, may mediate reduced cognitive function in individuals with high-level SCI (Phillips, Warburton, Ainslie & Krassioukov, 2014). Lastly, there were significant differences between SCI and OI group in a number of demographic, injury related and self-report variables. Even though the individuals in the control group had also an injury (ancle injury), the group was highly selected sample of previously healthy adults. The individuals in SCI group were older and there were more individuals identified as males in the group compared to the OI group. In the SCI group most individuals were retired full time, whereas most of the OI individuals were working full-time. Also, the SCI group reported more PTSS, pain and alcohol use overt the risk limits. Nearly 60 % of the SCI group used some CNS medication and the majority had findings in MRI. As a group, the SCI participants had lots of factors possibly affecting cognition. This setting reflects the typical challenge in SCI cognition research and having a control group. Hence, it´s important to use control groups sampled from the same population when studying cognitive functioning in SCI and include another injury group (for controlling pain).

The strengths of this study are a cervical SCI group, another injury group as

a control group, using a comprehensive motor-free neuro-psychological assessment battery and using standardized and well-known assessment methods. Also, cognitive impairment is defined properly based on criterion from scientific studies. Detailed data collection was performed, and several important factors were controlled for. And even though the study did not investigate the association of cognitive functioning and brain structures, we had the individual MRI-data of SCI individuals.

In conclusion, the results of this study imply that cognitive impairment is a salient factor to consider in chronic cervical TSCI, but most of the population function cognitively within normal limits. Educational level is important to consider in neuro-psychological assessment to avoid false positive evaluations of cognitive impairment. Pain management is of essence to support cognitive functioning in SCI.

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Appendix

Table a1. Results of the multivariate regression model for predicting variance in test performance in neuropsychological measures

Dependent variable: COWATanimals

Variables	*B*	SE B	β	p	
Group	-3.96	1.75	-0.32	0.027	*
Sex	-0.98	1.50	-0.08	0.518	
Age	-0.02	0.05	-0.05	0.711	
Education	0.53	0.21	0.30	0.012	*
Pain	1.26	2.75	0.07	0.647	
PTSD	-3.88	2.85	-0.20	0.179	
R2	0.32				
Adjusted R2	0.25				
	F(6,61) = 4.72***				

Dependent variable: RAVLTtotal

Variables	*B*	SE B	β	p	
Group	2.35	2.32	0.12	0.315	
Sex	-6.84	1.99	-0.35	0.001	**
Age	-0.29	0.07	-0.45	<0.001	***
Education	0.08	0.28	0.29	0.007	**
Pain	-0.04	0.31	-0.02	0.893	
PTSD	-0.10	0.12	-0.10	0.426	
R2	0.48				
Adjusted R2	0.43				
	F(6,61) = 9.42***				

Dependent variable:WAISpicture

Variables	*B*	SE B	β	p	
Group	-2.46	1.00	-0.35	0.017	*
Sex	0.54	0.86	0.08	0.530	
Age	-0.04	0.03	-0.19	0.158	
Education	0.12	0.12	0.12	0.319	
Pain	-0.09	0.14	-0.10	0.527	
PTSD	0.00	0.05	0.01	0.966	
R2	0.30				
Adjusted R2	0.23				
	F(6,61) = 4.30***				

Dependent variable:WAISsimilar

Variables	*B*	SE B	β	p	
Group	-0.03	1.34	-0.00	0.985	
Sex	0.17	1.15	0.02	0.886	
Age	-0.07	0.04	-0.23	0.101	
Education	0.32	0.16	0.26	0.048	*
Pain	-0.01	0.18	-0.01	0.939	
PTSD	-0.07	0.07	-0.16	0.320	
R2	0.19				
Adjusted R2	0.11				
	F(6,61) = 2.43***				

Dependent variable:PASATtot

Variables	*B*	SE B	β	p	
Group	0.92	3.03	0.04	0.763	
Sex	3.76	2.60	0.15	0.154	
Age	-0.24	0.09	-0.30	0.014	**
Education	0.68	0.36	0.20	0.063	
Pain	-1.45	0.41	-0.47	<0.001	***
PTSD	0.06	0.16	0.05	0.729	
R2	0.44				
Adjusted R2	0.38				
	F(6,61) = 7.83***				

Dependent variable:STROOPtot

Variables	*B*	SE B	β	p	
Group	-3.31	2.73	-0.15	0.229	
Sex	-0.40	2.34	-0.02	0.866	
Age	-0.26	0.08	-0.36	0.003	**
Education	0.86	0.32	0.28	0.010	*
Pain	-0.16	0.39	-0.06	0.674	
PTSD	-0.11	0.15	-0.10	0.458	
R2	0.44				
Adjusted R2	0.38				
	F(6,61) = 7.92***				

*** = p < 0.001, ** = p < 0.01, * p < 0.05.