The Role of Aging in Patients with Acute Acquired Brain Injury: The Course of Executive Control and Information Processing Speed and their Association with Fatigue and Participation

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Abstract

Objective: The aim of this study was (1) to investigate the course of cognitive functioning in adult patients with acute Acquired Brain Injury (ABI), and (2) to examine how cognitive functioning relates to self-reported fatigue and participation in the chronic phase.

Method: In a retrospective cohort study, twenty-five patients with acute ABI were assessed with tests measuring information processing speed and executive control (Vienna Test System, Trail Making Test and Digit Span Test) within the first months post-ABI and at follow-up examination at least 5 years after sustaining the injury. Additional outcome measures were mental and physical fatigue levels (Dutch Multifactor Fatigue Scale) and level of participation (Utrecht Scale for Evaluation of Rehabilitation-Participation) at follow-up examination.

Results: Overall, patients with ABI demonstrated relatively stable cognitive functioning between the two moments of measurement, yet some significant improvements were found on measures of processing speed and mental flexibility. Patients with complaints of physical fatigue obtained poorer scores on measures of information processing speed at follow-up examination. Higher self-reported participation was associated with better information processing speed and mental flexibility as well as fewer complaints of physical fatigue.

Conclusions: Adult patients with ABI exhibit a relatively stable course of cognitive functioning over time, showing even improvements on measures of mental flexibility and information processing speed. Despite this positive aspect, complaints of fatigue are frequently reported in the chronic phase and are associated with both reduced information processing speed and participation-satisfaction. Our findings emphasize the importance of closely monitoring cognitive and fatigue-related complaints during the chronic phase in patients with ABI, with timely intervention when indicated.

Keywords: acquired brain injury, aging, cognition, fatigue, participation

Introduction

Acquired Brain Injury (ABI) is a prevalent condition directly or indirectly contributing to long-term impairments and disabilities (Corrigan & Hammond, 2013; Hammond et al., 2021). In the Netherlands, an estimated 140.000 people sustain brain injury annually and in total there are around 650.000 people who live with the disabilities as a consequence of ABI (Hersenz.nl). Traumatic brain injury (TBI) results from external forces, including a bump to the head or penetrating had injury, whereas non-traumatic brain injury (nTBI) is caused by internal mechanisms like stroke (Eapen & Cifu, 2021). The increasing rate of ABI globally constitutes a major socioeconomic problem leading to substantial healthcare costs (Maas, Stocchetti, & Bullock, 2008; Gilmore, Mirman, & Kiran, 2021). Besides, the significance is demonstrated by the potential neurobehavioral sequelae associated with the injury. For the purpose of this study, ABI is used as an umbrella term to refer to any acute focal or diffuse injury of the brain occurring after birth, caused by external or internal forces (Giustini, Pistarini & Pisoni, 2013).

The consequences of ABI include cognitive, psychosocial, and physical impairment, often resulting in lifelong disability (Ponsford et al., 2014). Most prevailing cognitive deficits include mild, moderate, or severe impairments in the domains of attention, information processing speed, and executive functioning (Gardner et al., 2018; Moretti et al., 2012). Additional frequently reported symptoms are irritability, headaches, depression, anxiety, and fatigue (Hoofien, et al., 2001). While the cognitive outcome of ABI beyond 2 years and up to 5 years post injury has increasingly been studied, limited research has examined cognitive functioning over time beyond 5 years post injury in adult patients with ABI (Hicks et al., 2022).

Undoubtedly, the aging brain experiences normal structural and functional alterations, mainly in the frontal and temporal regions (Park & Reuter-Lorenz, 2009; Head et al., 2002). According to the scaffolding theory of aging and cognition (STAC) proposed by Park and

Reuter-Lorzenz (2009), increased frontal activation seen in the aging brain is indicative of an adaptive brain function. Cognitive function is protected by compensatory scaffolding using alternative neural circuits, in response to cortical atrophy. The functions supported by the frontal and temporal regions, most affected in aging, pose a double risk of functional decline after sustaining TBI compared to other functions (McAllister et al., 2006; Verstraeten et al., 2022). The heightened risk arises from the increased vulnerability of these regions after sustaining TBI and particularly affects executive functioning and processing speed.

Longitudinal studies examining the trajectory of cognitive functioning after sustaining ABI demonstrate heterogenous results. Ashman and colleagues (2008) identified stability in cognitive functioning over short time spans (2 to 5 years) based on norm scores in older adults with ABI. Wood and Rutterford (2006) found a relatively stable pattern of cognitive functioning over 16 years on a measure of abstract reasoning, with even improvement on measures of information processing speed and working memory. Conversely, Himanen and colleagues (2006) reported a slight cognitive decline in norm scores over a follow-up period of 30 years in general. However, no deterioration was found in approximately half of the patients and some patients demonstrated even improved performance on some memory tests.

Possibly, to maintain an overall stable level of cognitive functioning over time, patients with ABI require increased mental effort to compensate for cognitive deterioration caused by both injury and aging (Ziino & Ponsford, 2006; Ouellet & Morin, 2006; Scheibel, 2017). This elevated mental effort might result in increased levels of mental fatigue in patients with ABI. Kohl and colleagues (2009) proposed a possible mechanism underlying the association between mental fatigue and cognition in patients with TBI. Their study, using functional Magnetic Resonance Imaging (fMRI), found increased activation in brain areas related to cognitive control in patients with moderate-to-severe TBI compared to healthy controls during a series of neuropsychological tests. The increased brain activation could potentially indicate

heightened mental effort and mental fatigue. While mental fatigue has been associated with worse cognitive functioning in patients with ABI, studies demonstrate no relationship between physical fatigue and measures of cognition (Ziino & Ponsford, 2006; Rakers 2022).

Complaints of mental as well as physical fatigue following ABI are prevalent (45-73%) (Lindeman & van Der Naalt, 2020; Borgaro et al., 2009, Kohl et al., 2009) and interfere with independence, participation in daily activities, and return to work (Lagogianni, Thomas & Lincoln, 2018; Glader Stegmayr & Asplund, 2002; Jokinen et al., 2015). Previous studies observed improvements in participation within the first year after stroke, but found restrictions to persist and stabilize between one and three years post-stroke (de Graaf et al., 2022). Considering the goal of reintegration into productive activity during rehabilitation following ABI, fatigue may jeopardize successful rehabilitation (Chen et al., 2021). Furthermore, fatigue has the potential of becoming a chronic problem (Johansson, Berglund & Ronnback, 2009).

Conclusive research into the long-term trajectory of cognitive functioning in adult patients with ABI is lacking and the current literature examining the association between cognitive functioning and fatigue may have limitations regarding to how they relate to participation in the chronic phase. Furthermore, for effective treatment planning, it is crucial to comprehend whether cognitive status changes over time after sustaining ABI.

This study aimed to explore the course of executive control and information processing speed of patients with acute ABI, along with how cognitive functioning relates to self-reported fatigue and participation in the chronic phase. We hypothesized that in the subacute phase after sustaining ABI, the norm scores on neuropsychological tests are similar to those observed at follow-up examination, as they are adjusted for age. Moreover, significant negative correlations between measures of cognition and mental fatigue were expected. It was also hypothesized that participation would be positively associated with measures of cognition and negatively associated with mental and physical fatigue in the chronic phase.

Method

Participants and Procedures

All eligible patients who sustained an acute ABI resulting from traumatic brain injury, stroke, or subarachnoid hemorrhage, that have been admitted to the University Medical Centre Groningen (UMCG), and met the following inclusion criteria were approached for the retrospective cohort study: (a) age between 50-67 years; (b) diagnosis of acute ABI at hospital admission including abnormalities at the brain-Computed Tomography or Magnetic Resonance Imaging scan; (c) being able to independently complete questionnaires; (d) having sustained ABI after the age of 25; (e) having sustained ABI more than 5 years ago; (f) not currently living in a long-term care facility; (g) independent regarding activities of daily living; (h) access to earlier neuropsychological assessment that is completed within the first months after injury. Exclusion criteria were the presence of psychiatric, other neurological, and suspected neurodegenerative disease. Furthermore, patients accompanying disease with reduced life expectancy and patients who abuse drugs or alcohol were excluded from the sample. This project has been approved by the Ethics Committee UMCG.

Measures

Neuropsychological assessment at follow-up examination included a short neuropsychological test battery measuring memory, executive functioning, attention, intelligence, social cognition, and information processing speed. The test battery lasted approximately 90 minutes and was conducted in an isolated office by qualified assessors. Only measures of executive control and information processing speed, fatigue, and participation were employed in this study. Fatigue and participation questionnaires were sent to the participants prior to follow-up examination.

Measures of Cognition

Vienna Test System. The Vienna Test System (VTS) is a computerized assessment tool designed to objectively measure information processing speed, attentional control, and response inhibition (Schuhfried, 2013). When performing the VTS Reaction Tests (RT-S1, RT-S2, and RT-S3), the participant is required to press a reaction key on the response panel and return their finger to the rest key as fast as possible when relevant stimuli are presented. Decision time was computed for all used VTS RT subtests, with higher time scores indicating a lower performance. The VTS Determination Test (DT-S1) measured the number of correct responses, by pressing the appropriate buttons on the panel and pedals, to visual and auditory stimuli. Here, higher scores indicate a better performance. Percentile scores corrected for age and gender were derived from raw test scores.

Trail Making Test. The Trail Making Test (TMT) (Reitan & Wolfson, 1985) is a paper-and-pencil instrument that measures of attention, processing speed, and mental flexibility. In part A of the TMT (TMT-A), the time needed to connect 25 encircled numbers in the correct order from 1 to 25 using a pencil was measured. Part B of the TMT (TMT-B) measured the time needed to connect 25 encircled numbers and letters in alternating order. The B/A ratio score was utilized as a measure of cognitive flexibility while correcting for basic psychomotor speed. Patient data were compared to normative data matched for age and level of education.

Digit Span Test. The Digit Span is a neuropsychological test included in the Wechsler Adult Intelligence Scale - III (WAIS-III) (Wechsler, 1997) used to measure working memory and attention. The participant was asked to duplicate numbers in identical order or to repeat the numbers backwards as read aloud by the examiner. For both conditions the scores were summed up, resulting in total scores ranged from 0 to 32 with higher scores indicating superior performance. Raw scores were compared to normative data matched for age.

Self-report Measures for Fatigue, Participation and Satisfaction

Dutch Multifactor Fatigue Scale. Mental and physical fatigue in the chronic phase of ABI were assessed using the Dutch Multifactor Fatigue Scale (DMFS) developed by Visser-Keizer and colleagues (2015). The subscale mental fatigue (DMFS-M) contains 7 items from which a score between 7 and 35 could be derived, with higher scores implying increased mental fatigue. The physical fatigue subscale (DMFS-Ph) includes 6 items with scores ranging from 6 to 30. Increased physical fatigue is indicated by higher scores.

Utrecht Scale for Evaluation of Rehabilitation-Participation. The Utrecht Scale for Evaluation of Rehabilitation-Participation (USER-P) is a 32-item questionnaire employed to measure the participation level of the patients in the chronic phase of ABI (Post et al., 2012). The frequency scale (USER-P F) covers items on the frequency and hours of vocational, leisure, and social activities in the past 4 weeks. The restrictions scale (USER-P R) comprises items on encountered restrictions in participation of daily life as a consequence of the brain injury. The level of gratification concerning vocational, leisure, and social relationships was measured using the satisfaction scale (USER-P S). For the scope of this study, only the satisfaction scale and frequency scale were included. Total scores, for both the frequency and satisfaction scales, range from 0 to 100 with high scores indicating better participation or more satisfaction than lower scores.

Statistical Analysis

The data analysis included multiple analysis using the Statistical Package for Social Sciences (SPSS 28.0 Version, Chicago, Illinois, USA). Demographic and injury-related characteristics were reported by means and range for continuous variables and frequencies and percentages for categorical variables. Descriptive statistics of test performances per moment of measurement presented percentile scores (M, SD) and the percentage of impaired scores (below the 8th percentile) for each neuropsychological test. Assumptions were

checked. Differences in mean percentiles between the two moments of data collection were analyzed per neuropsychological test with the paired t-test for parametric data or the Wilcoxon Signed Rank test for nonparametric data.

Pearson correlations or Spearman's correlations, for parametric or nonparametric data respectively, were used to explore the relationship between DMFS scores and neuropsychological test percentile scores at follow-up examination and between USER-P scores and neuropsychological test percentile scores at follow-up examination as well as DMFS scores.

USER-P F scores were dichotomized into two participation groups (reduced and heightened participation) using median split. Similarly, median split dichotomized USER-P S scores into two satisfaction groups (reduced and heightened satisfaction). Demographic differences and differences in mean percentiles of neuropsychological tests at follow-up examination between the two participation and satisfaction groups were analyzed using Chi-square tests, and independent t-tests for parametric data and Mann-Whitney U tests for non-parametric data. Pearson correlation coefficients for parametric data or Spearman’s correlation coefficients for nonparametric data were calculated to assess the relationship between mean percentile scores of cognitive performances and the DMFS subscales of physical and mental fatigue per participation and satisfaction group. A two-sided overall alfa level of .05 was set. Due to the explorative nature of the study, no correction for multiple testing was used. Pairwise deletion was utilized for missing data.

Hypotheses

H1) Paired t-tests for parametric data or Wilcoxon Signed Rank tests for nonparametric data demonstrate that the percentile scores of measures of cognition (Digit Span, VTS RT and DT, and TMT) at baseline examination do not significantly differ from the percentile scores at follow-up examination.

H2a) As demonstrated by Pearson correlations for parametric data or Spearman's correlation for nonparametric data, there is a significant relationship between measures of cognition (percentile scores of the Digit Span, VTS RT and DT, and TMT) and self-reported mental fatigue (DMFS-M). No relationships between measures of cognition and self-reported physical fatigue (DMFS-Ph) are expected.

H2b) As demonstrated by Pearson correlations for parametric data or Spearman's correlations for nonparametric data, there is a significant relationship between self-reported participation (USER-P F and USER-P S) and both percentile scores of measures of cognition (Digit Span, VTS RT and DT, and TMT) and fatigue (DMFS-M and DMFS-Ph).

H2c) There is a significant correlation between percentile scores of measures of cognition (Digit Span, VTS RT and DT, and TMT) and reported fatigue (DMFS-M) in the reduced and in the heightened participation groups (participation-frequency and -satisfaction), as demonstrated by Pearson correlations for parametric data or Spearman's correlation for nonparametric data. No relationships between measures of cognition and self-reported physical fatigue are expected in all participation groups.

Results

In total, twenty-five adults diagnosed with ABI and ranging from 50 to 67 years of age at follow-up examination (mean = 59.2 years, SD = 5.2) were included in the study. The average years of age at the baseline examination was equivalent to 50.8 years (SD = 5.6). Patient characteristics including demographic and injury data are presented in Table 1.

Table 1

Patient characteristics

Variable	Patients (*n* = 25)
Age at time of injury, years *M* (range)	49.4 (37.0-59.0)
Gender, Female (%)	10 (40%)
Educational level, (%)	
Low (level 1–4)	3 (12%)
Average (level 5)	13 (52%)
High (level 6-7)	9 (36%)
Type of ABI, (%)	
TBI	17 (68%)
CVA	8 (32%)
TBI levels of severity (GCS), (%)	
Mild (score 13-15)	9 (53%)
Moderate (score 9-12)	2 (12%)
Severe (score 4-8)	6 (35%)
CVA levels of severity (NIHSS), (%)	
Minor stroke (score 1-4)	5 (71%)
Moderate stroke (score 5-15)	2 (29%)
Time since injury at baseline examination, months *M* (range)	8.4 (1.0 – 26.0)
Time since injury at follow-up examination, months *M* (range)	117.3 (78.0 – 184.0)

Note. Educational level = Verhage classification system, 7-point scale ranging from 1 (*primary education only*) to 7 (*university education);* ABI = acquired brain injury; TBI = traumatic brain injury; GCS = Glasgow Coma Scale; CVA = cerebrovascular accident; NIHSS = National Institutes of Health Stroke Scale.

Course of Executive Control and Information Processing Speed

Table 2 demonstrates the group means, standard deviations, and percentages of impaired scores for each neuropsychological measure at baseline and follow-up examination. In addition, difference scores between baseline and follow-up examination are displayed.

Wilcoxon ranked analysis demonstrated significantly improved percentile scores of the VTS RT-S2 during the follow-up examination when compared to the baseline examination ($p < .05$). Similarly, the TMT-B subtest percentile scores as well as the B/A index scores were significantly higher during the follow-up examination than at baseline examination *(*$p < .01$ and $p < .05$, respectively).

Table 2

Course of cognitive performances over time based on raw and percentile scores and percentages of impaired scores, M (SD)

		1. Baseline examination			3. Follow-up examination			Difference 1 -2	
Variable	*n*	Raw scores	Percentile scores	Impaired (%)	Raw scores	Percentile scores	Impaired (%)	Percentile scores 1 - 2	*p*
Digit Span	11	15.3 (2.75)	41.6 (27.1)	0	14.2 (3.4)	47.8 (30.8)	0	+6.3 (23.2)	.424
VTS									
RT-S1	18	328.9 (77.2)	65.0 (26.0)	6	361.8 (113.1)	60.2 (31.5)	6	- 4.8 (34.4)	.528
RT-S2	19	270.7 (90.2)	75.4 (27.0)	0	285.3 (194.3)	84.7 (26.9)	0	+9.3 (20.6)	**.028***
RT-S3	19	460.7 (115.1)	42.7 (31.45)	11	527.9 (173.4)	38.1 (27.3)	21	-4.6 (20.9)	.305
DT-S1	15	209.9 (37.7)	35.3 (23.4)	13	205.1 (43.5)	40.1 (30.0)	13	+4.8 (24.9)	.551
TMT									
A	21	29.9 (13.6)	31.3 (32.5)	38	37.1 (10.7)	42.1 (25.8)	10	+10.8 (33.9)	.154
B	21	87.5 (33.5)	35.2 (30.5)	29	77.6 (39.3)	56.7 (32.7)	10	+21.5 (29.1)	**.004****
B/A	21		43.9 (27.6)	14		62.1 (30.2)	10	+18.2 (32.8)	**.022***

Note. VTS = Vienna Test System; RT = reaction test; DT = determination test; TMT = Trail making Test; B/A = ratio score; * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level.

Correlations between Measures of Cognition and Self-reported Fatigue

In Table 3, the correlation coefficients between measures of cognition and self-reported fatigue are presented. Moderate to strong negative correlations were found between the DMFS-Ph and the VTS-RT-S1, the VTS-RT-S2, and the VTS-DT-S1 at follow-up examination ($p < .01$, $p < .05$ and $p < .01$ respectively).

Table 3

Spearman's Rho correlations between percentile scores of measures of cognition at follow-up examination and self-reported fatigue

Variable	DMFS-M *n* = 24	DMFS-Ph *n* = 24
Digit span	.06	-.40
VTS		
RT-S1	.23	**-.56****
RT-S2	.13	**-.50***
RT-S3	.13	-.18
DT-S1	.02	**-.60****
TMT		
A	.27	-.15
B	.10	-.25
B/A	.04	-.26

Note. DMFS-M = mental fatigue subscale of the Dutch Multifactor Fatigue Scale (DMFS); DMFS-Ph = physical fatigue subscale of the DMFS; VTS = Vienna Test System; RT = reaction test; DT = determination test; TMT = Trail making Test; B/A = ratio score; * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level.

Correlations between Self-reported Participation and Measures of Cognition and Correlations between Self-reported Participation and Fatigue

The correlation coefficients between percentile scores of measures of cognition at follow-up examination and self-reported participation are displayed in Table 4. Moderate positive correlations were found between the self-reported participation frequency scale and percentile scores of the VTS-RT-S1 and VTS-RT-S2 ($p < .05$ and $p < .05$, respectively). Participation-satisfaction moderately positively correlated with VTS RT-S1, TMT B/A

performances ($p < .05$ and $p < .05$, respectively) and moderately negatively correlated with self-reported DMFS-Ph ($p < .05$).

Table 4

Spearman's Rho correlations between self-reported participation and percentile scores of measures of cognition as well as self-reported fatigue at follow-up examination

Variable	USER-P F *n* = 24	USER-P S *n* = 24
Digit span	.18	.31
VTS		
RT-S1	**.51***	**.45***
RT-S2	**.53***	.41
RT-S3	.19	.28
DT-S1	.20	.34
TMT		
A	-.16	.05
B	.14	.36
B/A	.25	**.41***
DMFS		
M	-.06	-.18
Ph	-.34	**-.42***

Note. USER-P F = frequency subscale of the Utrecht Scale for Evaluation Rehabilitation-Participation (USER–P); USER-P S = satisfaction subscale of the USER-P; VTS = Vienna Test System; RT = reaction test; DT = determination test; TMT = Trail making Test; B/A = ratio score; * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level.

Correlations between Measures of Cognition and Self-reported Fatigue in Heightened and Reduced Participation Groups and Differences in Measures of Cognition and Self-reported Fatigue between Participation Groups

Table 5 shows bivariate correlation coefficients between percentile scores of measures of cognition at follow-up examination and self-reported fatigue per participation frequency and satisfaction group. The heightened participation group demonstrated a strong negative correlation between the VTS-DT-S1 percentile scores at follow up and the subjectively reported physical fatigue subscale ($p < .05$). Better scores on the VTS- RT-S1 and the VTS-RT-S2 were strongly related to more self-reported mental fatigue in the reduced satisfaction group ($p < .001$

and $p < .05$ respectively). In the heightened satisfaction group, performance on the VTS-DT-S1 was moderately negatively correlated with physical fatigue ($p < .05$).

Table 6 (see Appendix A) presents the differences between the reduced and heightened participation group and between the reduced and heightened satisfaction group on the measures of fatigue and cognition at follow-up examination.

Although results in the heightened participation frequency and satisfaction groups demonstrate a trend from lower fatigue scores and higher percentile scores on measures of cognition when compared to the reduced participation frequency and satisfaction groups, overall differences were not significant.

Mann-Whitney U tests reported significant higher mean percentile scores on the VTS-RT-S2 in the heightened frequency group compared to the reduced frequency group ($p < .05$).

Chi-square test demonstrated significantly more women in the reduced satisfaction group compared to the heightened satisfaction group ($p < .05$). The reduced satisfaction group experienced significantly more physical fatigue compared to the heightened satisfaction group ($p < .05$).

Table 5

Spearman's Rho correlations between fatigue scores and neuropsychological test percentile scores at follow-up examination per participation group (frequency and satisfaction scale)

	Reduced participation *n* = 12		Heightened participation *n* = 12	
Variable	DMFS-M	DMFS-Ph	DMFS-M	DMFS-Ph
Digit span	.06	-.57	.10	-.24
VTS				
RT-S1	.29	-.33	.27	-.51
RT-S2	.27	-.15	.21	-.43
RT-S3	.24	.17	.21	-.22
DT-S1	-.02	-.50	-.11	**-.64***
TMT				
A	.10	-.15	.02	-.32
B	.22	-.45	-.11	-.03
B/A	.26	-.41	.05	.02

	Reduced Satisfaction *n* = 12		Heightened satisfaction *n* = 12	
Digit span	.38	-.18	-.16	-.39
VTS				
RT-S1 DT	**.80****	-.29	-.24	-.28
RT-S2 DT	**.72***	-.35	-.54	-.21
RT-S3 DT	.44	-.07	-.17	.04
DT-S1	.29	-.40	-.21	**-.69***
TMT				
A	.43	-.10	.13	-.37
B	.42	-.09	.01	-.31
B/A	.23	-.08	.01	-.30

Note. DMFS-M = mental fatigue subscale of the Dutch Multifactor Fatigue Scale (DMFS); DMFS-Ph = physical fatigue subscale of the DMFS; VTS = Vienna Test System; RT = reaction test; DT = determination test; TMT = Trail making Test; B/A = ratio score; * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level.

Discussion

The objective of the current study was to investigate the course of executive control and information processing speed and explore the relationship between cognitive functioning, fatigue, and participation in adult patients with ABI. Overall, results indicated a relatively stable course of cognitive functioning over time after ABI, with significant improvements in information processing speed and mental flexibility at follow-up examination. Furthermore, better information processing speed was significantly related to lower levels of subjectively reported physical fatigue. Higher self-reported participation was significantly associated with better information processing speed and mental flexibility as well as diminished subjectively reported physical fatigue. Better basic information processing speed was significantly related to more mental fatigue in the reduced satisfaction group. Lastly, increased complex information processing speed was related to lower levels of physical fatigue in the heightened participation (-satisfaction) group.

As hypothesized, patients with ABI demonstrate relatively stable performance when corrected for the effects of age, on tests tapping into information processing speed and mental flexibility between the baseline examination and follow-up examination conducted at least 5 years after sustaining ABI. These findings suggest that, in this group of adult patients with ABI, compensatory scaffolding may have played a role in retaining normal cognitive task performance (Park & Reuter-Lorenz, 2009). Our results also indicated significant improvement on 3 out of 8 neuropsychological tests suggesting that recovery may continue at least for some patients with ABI after the 6- to 12- month period as proposed by previous research (Dikmen, Reitan, & Temkin, 1983; Levin, 1995; Wood & Rutterford, 2006). Tasks involving both processing speed and mental flexibility demonstrated improvement over time, which could indicate that timed tasks have the most sensitivity to late recovery after ABI. Our results align with earlier studies highlighting heterogeneity in long-term cognitive outcome in patients with

ABI, with most improvement found on timed tasks and tasks requiring complex constructional skills (Millis et al., 2001; Ruff et al., 1991). It is important to note that even though the neuropsychological test scores do not show cognitive decline on a group level, research has shown that patients may still experience (cognitive) complaints in daily life (Jamora, Young, & Ruff, 2012; Burgess, 2006).

Surprisingly, no significant associations between the objective measures of cognition at follow-up examination and self-reported mental fatigue were found in this study. One possible explanation for this finding could be the heterogeneity of the sample. Previous studies established that patients with moderate-severe TBI in the subacute to chronic phase perform significantly worse on tasks of information processing speed compared to those with mild TBI (Rakers, 2022; Ouellet & Morin, 2006; Scheibel, 2017). This decreased processing speed mainly found in patients with moderate-severe TBI imposes heightened brain activity, correlating with elevated levels of mental fatigue. However, our sample encompassed a wide range of acquired brain injuries potentially affecting different cognitive domains, which might have contributed to the lack of uniform associations.

Higher levels of self-reported physical fatigue were moderately associated with slowing of information processing speed at follow-up examination. Various studies however, reported no association between physical fatigue and measures of executive control or information processing speed (Ziino & Ponsford, 2006; Rakers, 2022). An explanation for our findings is that the high levels of self-reported fatigue may partly reflect the psychological distress experienced by the patients (Schiehser et al., 2017). As previously, psychological distress has been related to worse cognitive performance in patients with ABI (Uiterwijk et al., 2022), it is possible that such factors might have confounded the objective cognitive measures, contributing to significant findings.

Interestingly, subjectively reported participation and satisfaction were moderately positively related to levels of processing speed and mental flexibility at follow-up examination. A similar positive relationship between participation (-satisfaction) and cognitive functioning was found in a previous study at 1 year post stroke (Verhoeven et al., 2010), however our study suggests this relationship also exists in adult patients with ABI. Furthermore, higher self-reported participation-satisfaction was moderately associated with lower self-reported physical fatigue. No associations were found between self-reported fatigue and participation frequency, which is contrary to our expectations, but in line with previous research (Cantor et al., 2008). They suggested that patients with ABI do not generally reduce their engagement in major life activities because of fatigue, but instead may experience a decrease in quality of participation. Our findings partly support their hypothesis by suggesting that patients with ABI who experience elevated physical fatigue may encounter increased challenges and less fulfilling results in their participation. This underlines the need to explore participation as a multidimensional concept in patients with ABI, differentiating between quantity and quality of participation.

When taking participation into account, limited associations were found between self-reported mental as well as physical fatigue and cognitive functioning at follow-up examination. In the heightened participation frequency and satisfaction groups, strong associations remained between better complex processing speed and reduced physical fatigue. Findings also suggested that, in unexpected direction, higher levels of fatigue were strongly associated with better basic information processing speed in the reduced satisfaction group. These unexpected findings underscore the complexity of the interplay between cognitive functioning and fatigue in various participation groups.

This study comes with several limitations. The small sample size in this study is associated with lack of statistical power, problems of biased estimates of data and random

variation leading to correlation coefficients in opposite direction to what is expected. Furthermore, there is a lack of statistical power due to substantial amount of missing data, particularly at baseline examination. The use of pairwise deletion may have led to underestimation or overestimation of standard errors due to inconsistency in sample size (Baraldi & Enders, 2010). The ceiling effect found for self-reported mental fatigue might have also led to reduced power of statistics on our analyses (Wang et al., 2008). Considering the explorative design, no correction for multiple testing was used, leading to a higher likelihood of a Type I error. Self-reports were used to measure the level of fatigue and participation, hence answers could be influenced by lack of awareness or psychological factors (van Markus-Doornbosch et al., 2020; de Graaf et al., 2020; Prigatono, 2005). Future studies necessitate the use of larger samples and a control group to examine the sole impact of ABI on cognitive functioning. Examining the associations between cognition, participation, and fatigue in a larger cohort, along with identifying predictors of participation, is crucial to improve rehabilitation programs.

Although cognitive functioning in adult patients with ABI appeared to follow a relatively stable course over time, improvements were found in mental flexibility and information processing speed. Despite this positive finding, it is essential to note that patients with ABI reported elevated fatigue levels in the chronic phase. Significant associations between physical fatigue and information processing speed and a lack of associations between mental fatigue and cognitive functioning suggest a nuanced and complex relationship between fatigue and cognition in this population. In addition, significant associations between participation and both cognitive functioning and physical fatigue stress the need for longitudinal research with larger sample sizes. Our study underscores the necessity of ongoing monitoring of cognitive and fatigue-related complaints in patients with ABI in the chronic phase, and initiating intervention when needed.

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Appendix A. Table 6

Table 6

Difference scores of demographic variables, fatigue scores and neuropsychological test percentile scores at follow-up examination per participation group (frequency and satisfaction scale)

Variable	1. Reduced frequency	2. Heightened frequency	Difference 1 – 2	3.Reduced satisfaction	4.Heightened satisfaction	Difference 3 - 4
	(*n* =12)	(*n* =12)	*p*	(*n* =12)	(*n* =12)	*p*
Gender, Female (%)	7 (58%)	3 (25%)	.098	8 (67%)	2 (17%)	**.013***
Age at time of injury, years *M* (range)	45.9 (37.0-51.0)	52.1 (42.0-59.0)	.056	48.4 (37.0-59.0)	50.7 (42.0-59.0)	.525
Educational level, *M* (range)	4.4 (1.0-6.0)	5.58 (2.0-7.0)	.458	5.5 (1.0-6.0)	4.92 (2.0-8.0)	.179
Time since injury at follow-up examination, months *M* (range)	136.7 (78.0-184.0)	107.3 (81.0-180.0)	.146	110.0 (37.9)	122.5 (31.6)	.247
DMFS-M, *M* (range)	28.3 (11.0-34.0)	26.9 (18.0-35.0)	.117	27.9 (11.0-35.0)	27.8 (18.0-34.0)	.496
DMFS-Ph, *M* (range)	19.5 (13.0-28.0)	16.4 (11.0-24.0)	.077	19.8 (16.0-28.0)	16.1 (11.0-22.0)	**.038***
Digit Span, *M* (*SD)*	44.0 (27.3)	56.0 (32.4)	.298	41.4 (24.7)	59.6 (32.8)	.132
VTS, *M (SD)*						
RT-S1	45.4 (31.4)	72.4 (26.5)	.053	45.5 (32.0)	72.7 (24.9)	.053
RT-S2	72.7 (33.3)	91.7 (20.9)	**.022***	63.6 (40.4)	92.9 (12.3)	.089
RT-S3	28.4 (22.5)	43.3 (28.9)	.259	26.8 (23.8)	43.2 (29.0)	.192
DT-S1	28.2 (29.46)	40.6 (27.2)	.291	24.9 (22.7)	43.0 (31.4)	.275
TMT, *M* (*SD)*						
A	49.8 (30.8)	38.3 (21.3)	.260	46.2 (30.1)	42.1 (23.9)	.707
B	55.0 (34.6)	58.4 (29.2)	.840	49.4 (29.0)	59.9 (32.1)	.355
B/A	55.6 (28.5)	66.3 (28.8)	.386	51.3 (27.3)	67.2 (28.9)	.165

Note. Educational level = Verhage classification system, 7-point scale ranging from 1 (*primary education only)* to 7 (university education); DMFS-M = mental fatigue subscale of the Dutch Multifactor Fatigue Scale (DMFS); DMFS-Ph = physical fatigue subscale of the DMFS; VTS = Vienna Test System; RT = reaction test; DT = determination test; TMT = Trail making Test; B/A = ratio score; * = correlation is significant at the 0.05 level; ** = correlation is significant at the 0.01 level.