Deficits in Information Processing Speed and Attention in Aneurysmal and Angiographically Negative Subarachnoid Hemorrhage: Associations with Mental Fatigue and Cognitive Complaints

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Abstract

Background. Deficits in information processing speed and attention are frequently found in patients with aneurysmal subarachnoid hemorrhage (aSAH) but studies on angiographically negative subarachnoid hemorrhage (anSAH) are less clear. Both patient groups report high levels of fatigue and cognitive complaints. Our aim was to investigate deficits in information processing speed and attention in both patient groups by comparing them to healthy controls and to each other. Secondly, our aim was to investigate the relation between deficits in these domains and mental fatigue.

Method. Patients (N = 40) and healthy controls (N = 47) were assessed using the Trail Making Test (TMT) and the Vienna Testing System Reaction Time Task (VTS-RT) and Determination Task (VTS-DT), a test that has not been used before in these patient groups. Questionnaires were used to investigate cognitive complaints and mental fatigue. Between-group comparisons and correlational analyses were made.

Results. Both aSAH and anSAH patients scored significantly lower on the VTS tests of information processing speed and attention than healthy controls. Only, aSAH patients scored significantly lower on the TMT tests, while anSAH patients did not. Both patient groups report an equal number of cognitive complaints in these domains, and high rates of mental fatigue. Mental fatigue is most strongly related to subjective cognitive complaints and not to neuropsychological tests.

Conclusions. These findings show that information processing speed and attention impairments affect both aSAH and anSAH patients and cognitive complaints regarding these domains are related to mental fatigue. Furthermore, the present study shows that the VTS subtests may be preferred above the traditionally used TMT as a measure of information processing speed and attention as it was more sensitive to deficits in these domains while the TMT was not.

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Introduction

A subarachnoid hemorrhage (SAH) is a serious bleeding in the subarachnoid space, between the pia mater and dura mater. Although accounting for only 3-5% of all strokes, SAH has the highest morbidity and fatality rates (Feigin et al., 2009). Although the prevalence of SAH has decreased with 17% in the last 30 years, it still carries a morbidity rate of approximately 35% (Nieuwkamp et al., 2009). In 85% of the cases, a SAH is caused by the rupture of a brain aneurysm, which is called an aneurysmal subarachnoid hemorrhage (aSAH). In the rest of the cases no structural cause for the hemorrhage can be found, defined as an angiographically negative subarachnoid hemorrhage (anSAH) (Flaherty et al., 2005). Diagnosis of SAH is made based on CT scans or punctures of cerebrospinal fluid (Burke et al., 2020). In contrast to aSAH, anSAH patients do not require endovascular (coiling or stenting) or open surgical treatment (clipping or wrapping) and are regarded as having a good neurological prognosis and benign medical outcome (Kapadia et al., 2014; Rinkel et al., 1991). However, the neurotoxic effects of blood accumulated in the subarachnoid space together with secondary complications have been associated with cognitive impairments and can therefore also be present in anSAH patients (Burke et al., 2018).

Studies have found a broad range of cognitive domains being affected after aneurysmal SAH such as memory, attention, language, executive functions, and social cognition (Al-Khindi et al., 2010; Buunk et al., 2016). The cognitive outcome after anSAH is less studied and shows more conflicting findings. Some studies have found lower scores in divided attention, processing speed, mental flexibility, and memory (Boerboom et al., 2014; Hütter et al., 1994; Burke et al., 2020) and a systematic review of Burke et al. (2018) found that attention and executive function impairments are most reported in anSAH patients. In contrast, other studies found cognitive functions to be in the normal range (Krajewski et al., 2014; Buunk et al., 2016). Previous research has suggested that anSAH patients have a favorable prognosis compared to aSAH patients because there is no need of surgical or endovascular treatment and a higher risk of rebleeding (Rinkel, & Algra, 2011; Boswell et al., 2013). Indeed, clinical characteristics like type of treatment (Hütter et al., 2001) and bleeding pattern on CT-scan (Cánovas et al., 2012) have been found to play a role in neurocognitive outcome as well as the presence of vasospasm and hydrocephalus (Hütter et al., 2001).

Next to objective cognitive deficits, SAH patients report a range of subjective complaints. Cognitive complaints like memory-, concentration problems and mental slowness are often mentioned (Toomela et al., 2004; Passier et al., 2010) and mood disorders like apathy, depression and anxiety are highly prevalent in both aSAH and anSAH patients (Alfeiri et al., 2008; Al-Khindi et al., 2010; Caeiro et al., 2011). Although anSAH patients show a less clear pattern of cognitive deficits compared to aSAH patients, they equally report subjective complaints regarding cognition and psychological functioning. These complaints stay prevalent even beyond the acute phase after SAH and have a great impact on the lives of patients and their relatives (Buunk et al., 2015; Ackermark et al., 2017). Because of the relatively young age at which a SAH occurs (between 40 and 60 years), these consequences hit patients at a phase in their lives where they are still very active in occupational, social, and family activities.

One of the most commonly reported complaints that can influence functional outcome after SAH is fatigue. The prevalence of fatigue ranges from 31 to 90% and remains present even several years after the initial bleeding (Kutlubaev et al., 2012). This big difference in prevalence rate is partially due to the different assessment techniques previous studies have used to measure fatigue. Most studies considered fatigue as a unitary construct which they measured with a single question (Kutlubaev et al., 2012). Buunk et al., (2018) were the first to study fatigue in SAH patients as a multidimensional construct and found that it can best be divided in physical and mental fatigue. Mental fatigue is described as a sustained feeling of exhaustion and lack of initiative after performing mentally demanding activities, while physical fatigue is characterized as fatigue experienced after physical activity. Their study found high frequencies of both physical and mental fatigue; only the prevalence of mental fatigue was significantly higher than physical fatigue in both aSAH and anSAH patients. Moreover, only mental fatigue was significantly related to unfavorable functional outcome post SAH, while physical fatigue and mood disorders were not.

The underlying mechanisms of fatigue after SAH are relatively unknown. A study of Passier et al. (2011) found that fatigue one year after SAH was correlated with depression and anxiety, passive coping, and cognitive impairment. However, because of the correlational design of the study, it is uncertain whether the mood and coping problems were caused by the SAH itself. Indeed, Buunk et al. (2018) showed that mental and physical fatigue were more prevalent than mood disorders, meaning that a significant portion of patients experiencing fatigue were not depressed or anxious. This distinction between depression and fatigue is in accordance with other types of stroke, where post stroke fatigue is related to tissue damage and depression is not (Winward et al., 2009). One theory about the relationship between cognitive impairments and mental fatigue is the coping hypothesis of Van Zomeren and Van den Burg (1985) which postulates that fatigue is the result of a constant effort to maintain performance at a sufficient level while compensating for cognitive deficits in information processing and attention. This is an interesting theory considering the fact that previous studies have found cognitive deficits in information processing speed and attention after SAH and have found that measures of complex attention have added value in predicting return to work after SAH (Boerboom et al., 2014; Hütter et al., 1994; Buunk et al., 2016). The coping hypothesis could also explain why aSAH and anSAH patients equally report subjective cognitive complaints, mood disorders and fatigue while objective cognitive measures show no clear evidence for cognitive impairment after anSAH. The relation between neuropsychological tests of information processing speed and attention and mental fatigue has already been described in mild traumatic brain injury (mTBI) patients but has not yet been studied in SAH patients (Ziino, & Ponsford, 2006; Johansson et al., 2009).

The concepts of processing speed and attention are often used interchangeably and are defined and measured in various ways. Spikman et al. (2001) studied the construct validity of attentional concepts and found two underlying constructs, namely speed/processing capacity and control/working memory. The concept of information processing speed can therefore be defined as requiring a high level of speed and low levels of control. When both speed and control are asked of the participant, a distinction can be made between focused and divided attentional tests. Traditionally, the Trail Making Test (TMT) is often used to measure these constructs, where part A is used as a measure of information processing speed and part B as a measure of divided attention. Because the TMT also requires visual search strategies and motor speed, a test that controls for the confounding effects of peripheral slowness or central slowness and that distinguishes between reaction and motor times may be more thoroughly to measure information processing speed and attention (Spikman & Van Zomeren, 2010). The Vienna Testing System (VTS) Reaction time task (RT) and Determination Task (DT) allows for this disentanglement but, to date, has not yet been applied to measure information processing speed and attention in SAH patients.

The aim of the present study was to investigate whether information processing speed or attention deficits exists in both aSAH and anSAH patients and to which extent these deficits differ between both patient groups. The second aim of this study was to investigate the relationship between information processing speed and attention with mental fatigue in both aSAH and anSAH patients and to compare this relationship between the two patient groups. It is hypothesized that SAH patients would perform worse on measures of information processing speed and attention as compared to healthy controls and that patients report more mental fatigue. Consistent with the coping hypothesis, it is hypothesized that poor performance on information processing speed and attention tests would be associated with higher subjective mental fatigue and that the relation between these two measures is stronger in anSAH patients for subjective measures of information processing speed and attention than objective tests of information processing speed and attention. Additionally, this study aims at comparing the performance of SAH patients on the VTS reaction time task and determination task and the more traditionally used TMT as measure of information processing speed and attention.

Method

Participants and Procedure

The present study was part of a larger prospective study (ICONS) at the University Medical Centre Groningen (UMCG). The study sample comprised SAH patients who were administered to the UMCG between December 2019 and October 2020. SAH was diagnosed using CT-angiography (CTA). Digital subtraction-angiography (DSA) or Magnetic Resonance Angiography (MRA) were used to determine the presence of an intracranial aneurysm (aSAH) or its absence (anSAH). Inclusion criteria were age older than 18 years at the time of SAH, sufficient capability of the Dutch language and sufficient mental and physical condition to participate in the study. Patients received an information letter and informed consent form at their release form the hospital. A neuropsychological assessment was administered approximately 6 months post-SAH as part of the standard clinical care. Additionally, the present study included healthy controls that were recruited through convenience sampling and received an information letter whereafter they underwent neuropsychological assessment. Exclusion criteria for healthy controls was the presence of neurological conditions and/or psychiatric disorders. The study was approved by the Medical Ethical Committee of the UMCG. Prior to neuropsychological testing, all participants gave written informed consent.

Measurement Instruments

Information Processing Speed

The Trail Making Test A (TMT-A) was administered as a measure of processing speed (Reitan & Wolfson, 1993). In TMT-A, the subject must connect a series of 25 numbers in numerical order by drawing a line as fast as possible. The score is the time to complete part A in seconds. TMT has shown to be a reliable test with a sufficient internal consistency (Matarazzo et al., 1974).

The Vienna Testing System (VTS) Reaction time task (RT) s1 and s2 were included as a measure for information processing speed (Prieler, 2008). The VTS is a computerized testing system with a range of tests that can be used in the clinical field. Participants must react as quickly as possible to optical (RTs1) or acoustic (RTs2) signals. This involves laying a finger on a touch-sensitive rest key and pressing a black key when the stimulus appears. The use of this rest key and the black reaction key makes it possible to distinguish between reaction and motor time. Reaction time is defined as the time between the appearance of the stimulus and releasing the rest key. Motor time is the time between releasing the rest key and pressing the reaction key. The mean reaction time is measured in milliseconds.

Attention

TMT Part B (TMT-B) consists of 25 encircled numbers and letters which the subject must connect in numerical and alphabetical order, while alternating between the two. It is a measure of divided attention because the subject must alternate between two response categories (Bowie & Harvey, 2006; Spikman & Van Zomeren, 2010). The score is the time to complete in seconds.

VTS RTs3 and DTs1 (Prieler, 2008; Neuwirth & Benesch, 2007) are used as measures of attention. RTs3 is a choice reaction test which requires participants to respond only when they see a yellow light and hear a tone at the same time. It is considered a measure of focused attention because the participant must only react to a specific combination of stimuli and inhibit responses to the remaining stimuli (Spikman & Van Zomeren, 2010). For this test, the mean reaction time and motor time in milliseconds is calculated. DTs1 is a complex multi-stimuli reaction task involving both colored stimuli and acoustic signals to which the participants must react by pressing the appropriate button or foot-pedal. The task is considered a test of divided attention because participants must divide their attention between the rapidly changing stimuli and respond in various ways. The score is the number of correct responses. Both the RT as well as the DT has shown to have good reliability and validity (Neuwirth & Benesch, 2007; Prieler, 2008).

Subjective Measure of Information Processing Speed/ Attention

To subjectively measure complaints regarding information processing speed and attention, the Checklist for Cognitive and Emotional Consequence of Stroke (CLCE-24) was administered (van Heugten et al., 2007). This questionnaire is often used in clinical practice as a supportive aid during the clinical interview, to assess cognitive and emotional complaints after different types of stroke. The questionnaire consists of 15 items concerning cognitive complaints, and 7 concerning emotional complaints. For each item, the presence or absence (scoring 1 or 0, respectively) is indicated.

The following three items were used in this study:

- Item one: *“since the stroke, the patient has problems in doing two things at once.”*
- Item two: *“since the stroke, the patient has problems attending to things.”*
- Item three: *“since the stroke, the patient has problems in keeping up, has become slower.”*

If the sum of the three items is 0, this is labeled as having no subjective cognitive complaints. A sum of 1 and higher is labeled as having subjective complaints in information processing speed and/or attention. The CLCE-24 has shown to have good reliability and validity (Van Heugten et al., 2007).

Fatigue

The Dutch Multifactor Fatigue Scale (DMFS) was used to measure mental fatigue (Visser-Keizer et al., 2015). This questionnaire is used to assess the nature and impact of fatigue in the chronic phase after acquired brain injury and consists of 38 items ranging from 1: totally disagree to 5: totally agree. The items are divided into five subscales: Impact of fatigue, mental fatigue, physical fatigue, consequences of fatigue and coping with fatigue. Only the subscale Mental fatigue was used in the present study. This subscale consists of 7 items (range 7 to 35) and addresses the precursors and consequences of mental fatigue. Scores were compared to a norm group of 129 healthy controls with no neurological, psychiatric, or medical comorbidities. Scores above the 89th percentile were labeled as high. The subscale has a good reliability (Visser-Keizer et al., 2015).

Statistical Analysis

Analyses were performed with the Statistical Package for the Social Sciences (SPPS), Version 25. Descriptive statistics, including means, standard deviations and percentages were calculated for the aSAH, anSAH and control groups. The Dutch classification system of Verhage (Verhage, 1964) was used to score the educational levels of the participants. This system ranges from 1 (no primary school) to 7 (university degree) and was dichotomized as low (1-4) and high (5-7). Performances of patients and controls were examined using normative data provided by the test developers and as used in clinical practice. Performances below the 10th percentile were regarded as being impaired (Lezak et al., 2004). The distributions of the neuropsychological tests were checked for parametric assumptions using quantile-quantile plots (Q-Q) and Kolmogorov-Smirnov tests. Mean-scores (M) on the different tests were compared between aSAH, anSAH and healthy controls, using independent t-tests and in case of non-normality, Mann-Whitney U tests. Differences in percentages impaired between both patient groups and healthy controls were calculated using Fisher's exact x^2 test. Effect sizes were calculated for all between group comparisons using Cohen's d (Cohen, 1988). Pearson or Spearman correlations were calculated to examine associations of mental fatigue and the different neuropsychological tests. The association between mental fatigue and subjective cognitive complaints was examined using Pearson or Spearman correlations in case of non-normality. Overall Alpha level was set at 0.05 for all analysis. Bonferroni-Holm corrections were used in case of multiple comparisons (Holm, 1979).

Hypotheses

Research question: Do information processing speed and attention deficits exist in SAH (both aSAH and anSAH) patients compared to healthy controls, and if so, are these deficits related to subjective cognitive complaints?

H0: There are no deficits in information processing speed and attention between SAH (both aSAH and anSAH) patients as compared to healthy controls.

Ha: aSAH and anSAH patients perform worse on measures of information processing speed (TMT-A; VTS-RTs1; VTS-RTs2) and attention (TMT-B; VTS-RTs3; VTS-DTs1) compared to healthy controls, and these deficits are related to subjective cognitive complaints (CLCE-24; analyze with t-tests/Mann-Whitney U tests, Pearson/Spearman correlations and Fisher's exact x^2 test).

Research question: Do aSAH and anSAH patients differ in information processing speed and attention deficits and if yes, to which extent?

H0: There is no difference between aSAH and anSAH patients in information processing speed/attention.

Ha: There is a difference between aSAH and anSAH patients; aSAH patients perform worse on measures of information processing speed (TMT-A; VTS-RTs1; VTS-RTs2) and attention (TMT-B; VTS-RTs3; VTS-DTs1) compared to anSAH patients (analyze with t-tests/Mann-Whitney U tests).

Research question: Is there a relation between information processing speed and attention and mental fatigue in aSAH and anSAH patients?

H0: There is no relation between information processing speed/attention and mental fatigue in aSAH and anSAH patients.

Ha: Poor performance on information processing speed (TMT-A; VTS-RTs1; VTS-RTs2) and attention (TMT-B; VTS-RTs3; VTS-DTs1) is associated with higher mental fatigue (DMFS; analyze with Pearson/Spearman correlations and ANOVA).

Research question: Does the relation between information processing speed and attention and mental fatigue differ between aSAH and anSAH patients?

H0: There is no difference in the relationship between information processing speed and attention and mental fatigue between aSAH and anSAH patients.

Ha: In anSAH patients there is a stronger relation between subjective measures of information processing speed and attention (CLCE-24) and mental fatigue (DMFS) than for objective tests TMT and VTS subtests; analyze with Pearson/Spearman correlations).

Results

Demographic and Descriptive Data

A total of 40 patients and 47 healthy controls were initially included in this study. Data of one healthy control and three patients were excluded because of outlier data (3rd quartile + 3*interquartile range). Therefore, 37 patients (26 aSAH, 11 anSAH) and 46 healthy controls eventually were included. Demographic and SAH characteristics are shown in table 1. Table 2 shows performances of both patient groups and healthy controls on the neuropsychological tests and questionnaires and the percentages of patients who were impaired on these tests.

Table 1

Characteristics of SAH patients and healthy controls

Characteristic	aSAH (n= 26)	anSAH (n= 11)	Control (n= 46)
Sex, number of women	16 (61.5%)	5 (45.5%)	30 (65.2%)
Mean age at time of SAH, years (SD)	56.2 (14.3)	53.5 (10.9)	50.9 (12.4)
Time since SAH in months, mean (range)	5.4 (3 -18)	4.5 (4-5)	N/A
Educational level			
Low (1-4)	7 (26.9%)	1 (9.1%)	1 (2.2%)
High (5-7)	19 (73.1%)	10 (90.9%)	45 (97.8%)

Note. aSAH, aneurysmal subarachnoid hemorrhage; anSAH, angiographically negative subarachnoid hemorrhage.

Table 2

Performance on neuropsychological tests and questionnaires.

Measure	aSAH % impaired	anSAH % impaired	Controls % impaired	aSAH M (SD)	anSAH M (SD)	Controls M (SD)
Information processing speed						
TMT-A	20.0*	9.1	4.3	39.4 (16.9)	31.4 (8.4)	28.5 (7.6)
VTS_RTs1	0	0	0	307.0 (45.4)	322.5 (80.6)	259.8 (42.9)
VTS-RTs2	0	0	0	266.7 (44.7)	280.6 (95.8)	255.1 (42.6)
Attention						
TMT-B	12.0	0	2.2	81.7 (24.8	65.9 (11.4)	58.2 (15.9)
VTS-RTs3	0	36.4*	4.3	482.9 (82.1)	526.2 (106.1)	439.7 (71.7)
VTS-DTs1	32.0*	27.3	6.7	190.0 (29.2)	203.8 (30.4)	232.3 (30.8)
Questionnaires						
CLCE-24						
Number of people with complaints	N/A	N/A	\N/A	17 (65.4%)	9 (81.8%)	N/A
DMFS Mental Fatigue	N/A	N/A	N/A	22.7 (6.3)	22.1 (8.5)	17.7 (4.4)

Note. aSAH, aneurysmal subarachnoid hemorrhage; anSAH, angiographically negative subarachnoid hemorrhage; RT, Vienna Testing System Reaction time Task; DT, Vienna Testing System Determination Task; TMT, Trail Making Test; CLCE-24, Checklist for Cognitive and Emotional Consequence of Stroke; DMFS, Dutch Multifactor Fatigue Scale.

*significant difference in percentages impaired between patient group (aSAH or anSAH) and controls using one-sides Fisher's exact X^2-test ($p < 0.05$).

Comparison of aSAH and anSAH Patients and Healthy Controls

Table 3 shows the results of t-tests and Mann-Whitney U tests for the differences between aSAH patient, anSAH patients and healthy controls. aSAH patients scored significantly lower than healthy controls on all measures of information processing speed and attention. Effect sizes were moderate to large (Cohen's *d* between 0.56 and 1.38). anSAH patients scored significantly lower than controls on all VTS subtests (RTs1, RTs2, RTs3 and DTs1), but not on both conditions of the TMT. Effect sizes for the VTS subtests (RTs1, RTs2, RTs3 and DTs1) were moderate to large (Cohen's *d* between 0.52 and 0.95) and small to moderate for the TMT subtests. No significant differences were found between aSAH patients and anSAH patients on all tests, with effect sizes ranging between small and large (Cohen's *d* between 0.19 and 0.82). Also, no significant differences were found in reported subjective complaints on the CLCE-24 between aSAH and anSAH patients (Fisher's exact $X^{2\,=}$ 0.999, p = 0.445).

Table 3

Comparison between neuropsychological tests between aSAH patients, anSAH patients and healthy controls

	aSAH vs. controls			anSAH vs. controls			aSAH vs anSAH		
Measure	T/U	p	d[a]	T/U	p	d[a]	T/U	p	d[a]
Information processing speed									
TMT-A	324.5	**0.001**	0.77	-1.09	0.141	0.35	95.5	0.151	0.50
VTS-RTs1 reaction time	265	**0.000**	1.04	112	**0.002**	0.82	-0.75	0.460	0.24
VTS-RTs2 reaction time	259	**0.000**	1.06	159	0.029	0.52	-0.46	0.654	0.19
Attention									
TMT-B	-4.87	**0.000**	1.13	-1.52	0.067	0.56	2.01	0.053	0.82
VTS-RTs3 reaction time	-2.30	**0.012**	0.56	-2.57	**0.012**	0.95	-1.33	0.192	0.46
VTS-DTs1 Correct	5.49	**0.000**	1.38	2.76	**0.004**	0.93	-1.21	0.236	0.43

Note. aSAH, aneurysmal subarachnoid hemorrhage; anSAH, angiographically negative subarachnoid hemorrhage; TMT, Trail Making Test; VTS-RT, Vienna Testing System Reaction Time Task; VTS-DT, Vienna Testing System Determination Task.

[a] Cohen's d effect size.

Mental Fatigue and Tests of Information Processing Speed/ Attention

Compared to the normative group, 53.8% of aSAH patients and 54.5% of anSAH patients report high scores of mental fatigue. 10.3% of healthy controls reported high scores of mental fatigue. A significant difference was found between the three groups on the mental fatigue subscale (ANOVA, $F = 5.29$, $p = 0.008$). Planned contrast tests revealed that both aSAH patients (t (63) = 3.09, $p = 0.003$) and anSAH patients (t (63) = 2.07, $p = 0.042$) reported significantly more mental fatigue than healthy controls. There was no significant difference between the two patient groups (t (63) = -0.28, $p = 0.781$). As shown in table 4, significant moderate negative correlation between mental fatigue and the VTS-DTs1 were found for aSAH patients, indicating that lower scores on the VTS-DTs1 are associated with higher mental fatigue ($R^2 = 0.21$). For anSAH patients, a significant moderate positive correlation between VTS-RTs1 and mental fatigue as well as a a significant moderate negative correlation between TMT-B and mental fatigue were found. This indicates that slower reaction times on VTS-RTs1 and faster scores on the TMT-B are associated with higher mental fatigue ($R^2 = 0.36$ and $R^2 = 0.28$ respectively). None of the aforementioned correlations between mental fatigue and the TMT and VTS remained significant after applying Bonferroni-Holm corrections.

Mental Fatigue and Subjective Complaints of Information Processing speed/ Attention

For both aSAH and anSAH patients it is found that subjective cognitive complaints (CLCE-24) are associated with higher levels of mental fatigue, with a moderate effect for aSAH patients and a large effect for anSAH patients ($R^2 = 0.29$ and $R^2 = 0.67$ respectively). These correlations did not differ significantly between the two patient groups ($Z = -0.78$, $p = 0.435$). In aSAH patients, small to moderate correlations are found between all the VTS subtests and subjective cognitive complaints (CLCE-24). No significant relation was found for both TMT tests and the CLCE-24. None of the tests used to measure information processing speed and attention are correlated with subjective cognitive complaints in anSAH patients. After applying Bonferroni-Holm corrections, only the correlation between cognitive complaints and the VTS-RTs2 in aSAH patients, and mental fatigue in both patient groups remained significant.

Table 4

Pearson correlations between tests of information processing speed and attention, and questionnaires

	DMFS Mental Fatigue		CLCE-24	
Measure	aSAH	anSAH	aSAH	anSAH
Information processing speed				
TMT-A	-0.004	-0.08	0.15	0.05
	(0.492) +	(0.409)	(0.236) +	(0.441)
VTS-RTs1 Reaction time	0.04	0.60	0.38	0.32
	(0.424)	(0.027)*	(0.028)*	(0.167)
VTS-RTs2 Reaction time	0.24	0.36	0.54	0.07
	(0.115)	(0.140)	(0.002)**	(0.419)
Attention				
TMT-B	-0.13	-0.53	0.10	-0.37
	(0.269)	(0.049)*	(0.323)	(0.130)
VTS-RTs3 Reaction time	0.12	0.20	0.35	0.05
	(0.286)	(0.283)	(0.044)*	(0.448)
VTS-DTs1 Correct	-0.46	-0.48	-0.38	-0.05
	(0.010)*	(0.068)	(0.031)*	(0.440)
Questionnaires				
CLCE-24	0.54	0.82	N/A	N/A
	(0.002)**	(0.001)**		
DMFS Mental Fatigue	N/A	N/A	0.54	0.82
			(0.002)**	(0.001)**

Note. aSAH, aneurysmal subarachnoid hemorrhage; anSAH, angiographically negative subarachnoid hemorrhage; VTS-RT, Vienna Testing System Reaction Time Task; VTS-DT, Vienna Testing System Determination Task; TMT, Trail Making Test; CLCE-24, Checklist for Cognitive and Emotional Consequence of Stroke; DMFS, Dutch Multifactor Fatigue Scale.

+ Spearman's correlations were used, * significant < 0.05, ** significant after Bonferroni-Holm correction.

Discussion

In the present study, we found clear deficits in information processing speed and attention in both aSAH and anSAH patients. Our finding strengthens previous studies reporting deficits in these domains in aSAH patients (Al-Khindi et al., 2010; Buunk et al., 2016; Hütter et al., 1994) and anSAH patients (Alfieri et al., 2008; Burke et al., 2020; Hütter et al., 1994; Krajewski et al., 2014). Furthermore, the present study found that both patient groups report significantly more mental fatigue and subjective complaints regarding information processing speed and attention than healthy controls, and that the reported frequencies of these complaints do not differ between the two patient groups. Mental fatigue was most strongly associated with subjective cognitive complaints and not with neuropsychological tests of information processing speed and attention, in both aSAH and anSAH patients. To our knowledge, this is the first study that used the VTS as a measure of information processing speed and attention in SAH patients. Interestingly, in aSAH patients subjective cognitive complaints were related to the acoustic measure of information processing speed of the VTS, whilst the rest of the VTS subtests showed a trend towards a significant relationship. No such relationship between neuropsychological tests and cognitive complaints was found in anSAH patients, indicating a distinction between performances on tests of information processing speed and attention and subjective cognitive complaints in these domains in this patient group. This distinction in anSAH patients is in line with what is found in the previous studies of Buunk et al. (2016) and Toomela et al. (2004) where they also found no relation between performance on neuropsychological tests and reported cognitive complaints. This finding could be explained by the mechanisms proposed by the coping hypothesis (Van Zomeren & Van den Burg, 1985). It postulates that in order to compensate for reduced processing speed or attention, patients need to use more mental effort to keep performance at a normal level. This mental effort is subjectively experienced by the patient as a reduced cognitive function which is expressed as experiencing cognitive complaints. Indeed, the percentage of anSAH patients that report subjective cognitive complaints in information processing speed or attention is much higher than the percentage of patients that is impaired on neuropsychological tests in these domains.

Furthermore, in line with the coping hypothesis, we found that mental fatigue was most strongly associated with subjective cognitive complaints and not with neuropsychological tests of information processing speed and attention in both aSAH and anSAH patients. This indicates that the constant mental effort to compensate for reduced information processing speed or attention, expressed as cognitive complaints, is associated with more mental fatigue. This finding is in line with a recent study of Western et al. (2021) where they found that patients report a disproportionately large drainage of mental energy after executing cognitive tasks. An interesting finding in the present study, that is in support of the coping hypothesis, is a trend towards a moderate relationship between faster scores on the TMT-B and more mental fatigue in anSAH patients. anSAH patients are able to perform relatively well on this test with the consequence of more mental fatigue. This test of divided attention relies on both speed/processing capacity as well as control/working memory and therefore allows for compensation of one process when performance lacks in the other process. In this case it is likely to assume that a lack in performance on the speed/ processing capacity is compensated by an intact ability to exert control. Indeed, the VTS, which disentangles these processes, showed deficits in divided attention in anSAH patients, whilst the TMT-B did not. This suggests that the VTS is a preferred measure of attention and is more sensitive to attention deficits in this subgroup of patients. Due to the disentanglement of reaction times and motor times, the VTS controls for the confounding effects motor slowness has (peripheral slowness) on mental slowness (central slowness). A study on Parkinson's patients using the VTS-RTs1 showed that motor time, and not reaction time, was a significant predictor of patient's performance on the TMT-A even though patients did not differ in motor time compared to healthy controls (Vlagsma et al., 2016). To our knowledge, this relation has not yet been studied in SAH patients and may be an interesting subject for future research.

The theory that patients need to recruit additional recourses to keep performance at a normal level, resulting in cognitive complaints and mental fatigue, could be more extensively investigated with the use of brain imaging studies. To our knowledge only one such study has been performed in SAH patients. This fMRI study of Maher et al., (2015) found increased resting state connectivity in SAH patients which they suggest is related to increased mental fatigue as patients need to compensate for a particular brain region that is not properly engaged or activated by recruiting additional resources. More fMRI research on this topic has been done in mTBI patients, where the fMRI study of van der Horn et al., (2015) found that mTBI patients without cognitive complaints had a stronger deactivation of the default mode network (DMN), which indicates that these patients need less cognitive effort and therefor experience fewer (cognitive) complaints. Moreover, studies on TBI patients have established a relationship between an increased DMN at resting state and information processing speed and attention impairments, even in patients without focal injuries (Bonelle et al., 2011; Sharp et al., 2011). Possibly, a similar relation between increased resting state DMN and information processing speed and attention impairments may exist in SAH patients and may proof an interesting topic of research. fMRI research on this topic may give answers on the discrepancy between neuropsychological test performance and reported cognitive complaints, as well as its relationship with mental fatigue.

Several limitations in the present study must be considered before drawing conclusions. First, due to the small number of SAH patients included, this study lacks statistical power which may result in overestimation of effect sizes and reduces the likelihood that a significant result reflects a true effect. However, low statistical power also reduces the chance of finding a true significant effect and showing that a trend in the date is truly significant. Secondly, patients and controls were not matched on age, gender, or level of education, which may be important since age and sex seem to have an effect on information processing speed (Spikman & Van Zomeren, 2010). Furthermore, the present study did not consider the presence of mood disorders when assessing mental fatigue. Mood disorders are commonly reported after SAH (Tang et al., 2020; Vetkas et al., 2013) and several studies have shown its association with post-SAH fatigue (Buunk et al., 2018; Western et al., 2021). Even though fatigue and mood disorders are strongly related, these studies also showed that the majority of patients did not have mood disorders and therefore mood disorders and fatigue may be seen as two distinct phenomena. Lastly, the relationship between objective and subjective measures of information processing speed and attention and mental fatigue is only studied correlational. Other factors might be of influence on mental fatigue or reported subjective cognitive complaints, like the beforementioned mood disorders or coping strategies. In previous studies a relationship between passive coping style and fatigue has been found (Schepers et al., 2006) as well as an association between passive coping and lower scores on cognitive tests (Visser-Meily et al., 2009). Taking coping mechanisms into account when studying the relationship between deficits in information processing speed and attention and mental fatigue may therefore be of interest in future research.

In conclusion, the present study shows that information processing speed and attention deficits exist in both aSAH and anSAH patients. Furthermore, both patient groups report an equal number of subjective cognitive complaints in these domains, and high rates of mental fatigue. Mental fatigue is mostly related to subjective cognitive complaints and not to neuropsychological tests, although in aSAH patients the subtests of the newly used VTS show a trend towards a significant relation with mental fatigue. Furthermore, the present study shows that the VTS subtests may be preferred above the traditionally used TMT as a measure of information processing speed and attention. In anSAH patients, the VTS subtests showed deficits in these domains while the TMT did not. The VTS has the advantage of filtering out the effects of motor slowness, search strategies and visuo-motor skills and may therefore be more sensitive in patient groups with mild deficits. Since both attention deficits and mental fatigue have shown to be of influence on the resumption of daily live activities (Buunk et al., 2019; Western et al., 2021), it is important for clinical practice to assess these constructs thoroughly in order to alter interventions to the individual needs as best as possible.

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