Neuropsychiatric Disease and Treatment

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REVIEW

Cognitive impairment and memory dysfunction after a stroke diagnosis: a post-stroke memory assessment

This article was published in the following Dove Press journal:
Neuropsychiatric Disease and Treatment
9 September 2014
Number of times this article has been viewed

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Abstract: Cognitive impairment and memory dysfunction following stroke diagnosis are common symptoms that significantly affect the survivors' quality of life. Stroke patients have a high potential to develop dementia within the first year of stroke onset. Currently, efforts are being exerted to assess stroke effects on the brain, particularly in the early stages. Numerous neuropsychological assessments are being used to evaluate and differentiate cognitive impairment and dementia following stroke. This article focuses on the role of available neuropsychological assessments in detection of dementia and memory loss after stroke. This review starts with stroke types and risk factors associated with dementia development, followed by a brief description of stroke diagnosis criteria and the effects of stroke on the brain that lead to cognitive impairment and end with memory loss. This review aims to combine available neuropsychological assessments to develop a post-stroke memory assessment (PSMA) scheme based on the most recognized and available studies. The proposed PSMA is expected to assess different types of memory functionalities that are related to different parts of the brain according to stroke location. An optimal therapeutic program that would help stroke patients enjoy additional years with higher quality of life is presented.

Keywords: dementia, vascular dementia, memory, neuropsychological assessment

Introduction

Cognitive impairment and memory loss are common after a stroke. Approximately 30% of stroke patients develop dementia within 1 year of stroke onset.[1] Stroke affects the cognitive domain, which includes attention, memory, language, and orientation. The most affected domains are attention and executive functions; at the time of stroke diagnosis, memory problems are often prominent. Post-stroke dementia (PSD), particularly vascular dementia (VaD), reflects the vascular risk factors that are mostly correlated with cerebral vascular disease (CVD). Post-stroke cognitive impairment is the evolution of CVD that predisposes individuals to the vascular cognitive impairment (VCI) spectrum. Thus, understanding the VCI spectrum stages is necessary to evaluate the mental state of post-stroke patients, particularly the cognitive dysfunction and memory decline during the period following a stroke diagnosis. Until recently, no specific neuropsychological assessment to evaluate PSD including memory loss existed. Current efforts are focused on combining more than one of the available neuropsychological assessments to obtain a significant diagnosis of cognitive decline severity following a stroke. The aim of this study was to develop a post-stroke memory assessment (PSMA) based on the most popular and available neuropsychological assessments. The proposed PSMA is expected to assess different types of memory functionalities

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that are related to different parts of the brain according to the affected memory. Results are then correlated and related to the stroke location and severity. PSMA may provide a promising tool for evaluating post-stroke VaD and assisting medical doctors and clinicians in the assessment as well as evaluation of post-stroke memory impairment severity.

Stroke types

Stroke is considered a major cause of long-term physical disabilities in adults; it is the second most common cause of cognitive impairment and dementia and the third leading cause of death after coronary artery diseases and cancer.[2,3]

A stroke is a "brain attack" that is caused either by reducing blood and oxygen flow to the brain or by bleeding. Stroke can be classified into two main types: ischemic and hemorrhagic. Transient ischemic attack (TIA) is sometimes considered as the third type of stroke and can be referred to as a "mini-stroke."[4] Stroke characteristics are listed in Table 1.

Vascular risk factors and stroke diagnosis criteria

Numerous risk factors band to cause a stroke: modifiable risk factors, including age, sex, ethnicity, genetics; and non-modifiable risk factors, including CVD, heart disease, diabetes mellitus, hyperlipidemia, cigarette smoking, and alcohol abuse, as shown in Figure 1.[5,6] Stroke, which is considered a CVD, is an influential risk factor for cognitive impairment that eventually leads to the development of PSD.[7] Thus, stroke survivors require immediate medical control of these risk factors, which are modifiable, to reduce stroke prevalence.

Clinically, stroke can usually be diagnosed through typical symptoms and signs. Medical history is an early step of diagnosis and includes stroke onset, course, and patient information taken from patients' careers or relatives, followed by physical and neurological examinations of the patients. The neurological examination can be performed using the formal stroke scale developed by the National Institution of Health Stroke Scale[8] to classify early stroke severity. Laboratory testing is the next step; at this stage, blood tests are used to determine the blood sugar level and cholesterol level. This step is followed by an examination of the computer tomography/magnetic resonance imaging scan and electrocardiography recording to indicate stroke location and pulse irregularity, such as cardiovascular status, carotid bruits, fundus examination, peripheral vascular disease, and hypertension.[9] Electroencephalography is used to help differentiate between seizure and TIA or between lacunar and cortical infarction in occasional patients, as illustrated in Figure 2.[10]

Stroke effects on brain cerebrovascular function

The brain requires a constant supply of blood to carry oxygen and nutrients to the cortical neurons in order for it to function in a normal manner. Numerous arteries cooperate to achieve this demand. In the case where an ischemic or hemorrhagic stroke occurs in one or more of these arteries and/or their branches, it causes damage to a specific neuroanatomic location (ie, right hemisphere cortex, left hemisphere cortex, or subcortex, which can then be localized further to the frontal lobe, temporal lobe, parietal lobe, thalamus, for example). Thus, the part of the brain that does not get the blood it needs starts to die. Brain cellular damage and death within minutes of stroke onset is called the core, whereas the zone in which the blood decreases or marginal perfusion occurs is called the ischemic penumbra, as shown in Figure 3.[4,11]

Owing to the complexity of the neuronal networks concerned in cortical processes, the ischemic or hemorrhagic stroke that occurs in a specific vascular distribution and the damage to a neuroanatomic site typically impairs more than one cognitive function. Moreover, some stroke events may involve multiple neurologic systems that cause cognitive decline based on vascular distribution (ie, perceptual and sensory or motor and sensory), as tabularized in Table 2.[12]

Table 1 Classification of stroke

Classification of stroke and its subtypes		Definition
Ischemic stroke	Embolic	Blood flow blockage to the brain caused by the presence of blood clots in the arteries; the clots travel from the heart through the bloodstream to the brain.
	Thrombotic	Blood flow is impaired because of fat deposits, which cause blockage, on the wall of blood vessels.
Hemorrhagic stroke	Intracerebral	Bleeding within the brain tissues.
	Subarachnoid	Bleeding into the space between the inner and middle layers of the meninges.
Transient ischemic attacks		Attacks resulting from the temporary interruption of blood flow to the parts of the brain.

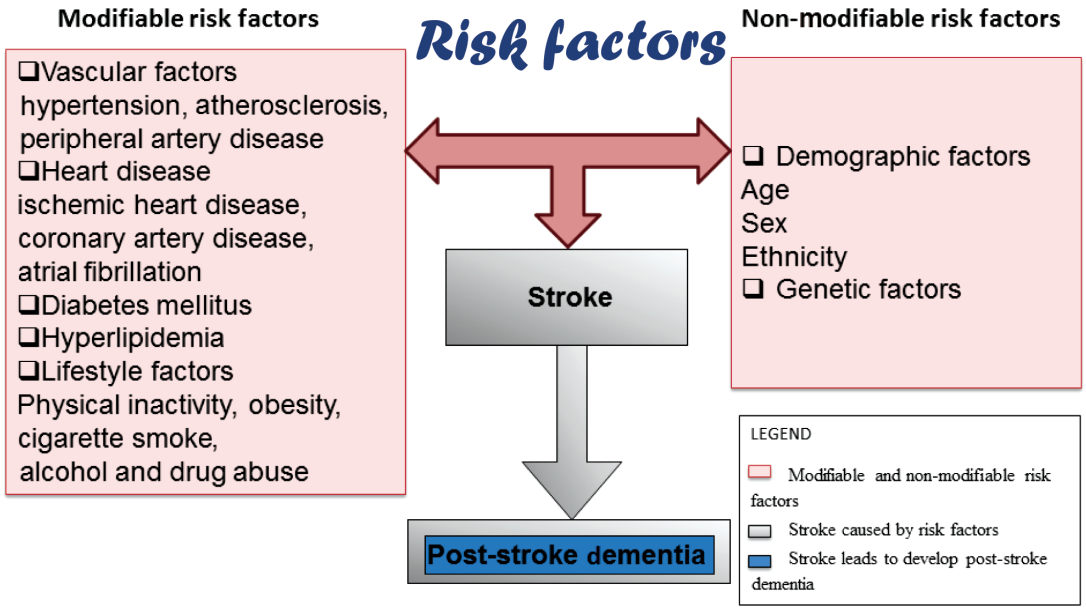

Figure 1 Risk factors and dementia.

Cognitive disorder following a stroke

Dementia is associated with neurodegenerative disorder diversity, neuronal dysfunction, and neuronal death. Dementia occurs when the brain is affected by a specific disease or condition that causes cognitive impairment.[13] In the case of a stroke, one or more cognitive domains may be affected, including attention, memory, language, and orientation. The highest impact of stroke at the time of diagnosis is on the attention and executive functions rather than on memory, which may be impaired at various post-stroke intervals. Previous studies show that post-stroke memory prevalence varies from 23% to 55% 3 months after stroke, ending with a decline from 11% to 31% 1 year after stroke onset.[3,14] Cognitive impairment after a stroke is common and leads to PSD. PSD includes all dementia types that occur after a stroke, including VaD; degenerative dementia, particularly Alzheimer's disease (AD); or mixed dementia (VaD plus AD).[2] VaD, the second leading cause of dementia in the world after AD, occurs as a result of stroke. Between 1% and 4% of elderly people aged 65 years and older suffer from VaD, and its prevalence will double every 5–10 years after this age.[15,16] VaD is characterized by impairment in the cognitive function due to vascular lesion and infarction resulting from the stroke. The clinical manifestation of VaD varies based on the size, location, and type of cerebral damage.[15] Figure 4 illustrates the cognitive impairment sequences which predispose individuals to the VCI spectrum.

The VCI spectrum can be viewed as a cognitive consequence in the cognitive domain, starting from mild cognitive impairment (MCI) and ending with severe dementia. The period beyond dementia in which the brain is at risk is called "cognitive impairment no dementia."[17]

MCI causes a more considerable decline in cognitive function with respect to individual age and education level, but not notably with the activities of daily life.[18,19] Clinically, MCI is the transitional stage between early normal cognition and late severe dementia, and it is considered heterogeneous because some MCI patients develop dementia while others stay and continue as MCI patients for many years. However, by default, patients diagnosed with MCI have a high

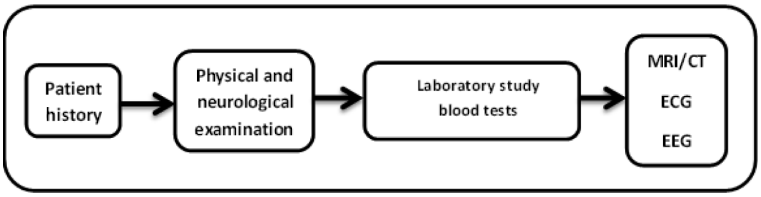

Figure 2 Clinical evaluation.
Abbreviations: CT, computed tomography; ECG, electrocardiography; EEG, electroencephalography; MRI, magnetic resonance imaging.

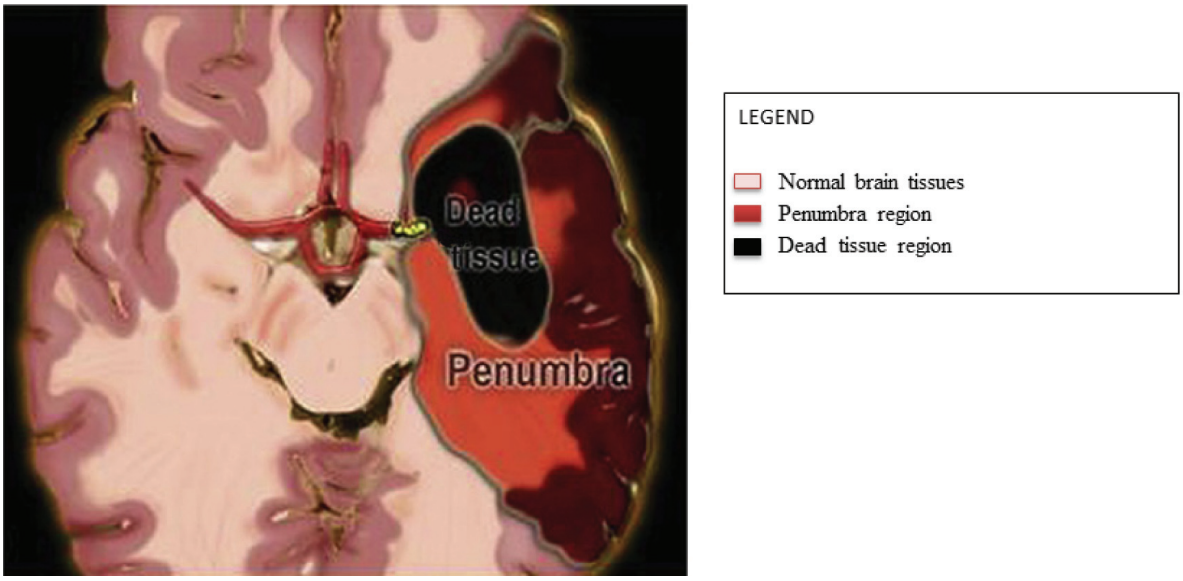

Figure 3 Core and penumbra after stroke.
Note: Reprinted from *Journal of Radiology Nursing*, 30(3), Summers D, Malloy R, CT and MR imaging in the acute ischemic stroke patient: a nursing perspective,104–115, Copyright 2011, with permission from Elsevier.[56]

Table 2 Stroke outcome due to vessel infarction

Brain artery infarction	Stroke outcome
Left middle cerebral artery	Aphasia
	Mutism
	Buccofacial apraxia
	Agraphia
	Acalculia
	Ideational apraxia
	Right/left confusion
Right middle cerebral artery	Neglect (personal, extrapersonal, and representational)
	Visuospatial failures and visuoconstructive disorders
	Aprosodia
	Language usage (pragmatic language)
	Disorders
	Anosognosia
	Anosodiaphoria
Posterior cerebral artery	Color agnosia
	Associative visual agnosia
	Alexia (hemianopic and pure)
	Facial agnosia
	Bálint's syndrome
	Amnesia
Anterior cerebral artery	Deficits in planning, initiation, monitoring, concentration, and flexibility
	Contralateral leg weakness
	Sensory loss
Subcortical infarcts	Impaired arousal, attention, motivation, initiation, and executive function
(include thalamic infarcts)	Memory (verbal, visual, episodic declarative, anterograde, and retrograde)
Caudate infarcts	Impaired problem solving and attention
	Memory
Subcortical	Confusion
(infarcts of the inferior genu of the internal capsule)	Memory disturbance
Subarachnoid hemorrhage	Amnesia
(anterior communicating artery aneurysm)	Personality changes
	Confabulation
	Abulia due to damage to the mesial frontal cortex
Limbic and paralimbic lesion	Implicated in a failure to learn and retain new information
	Affective changes

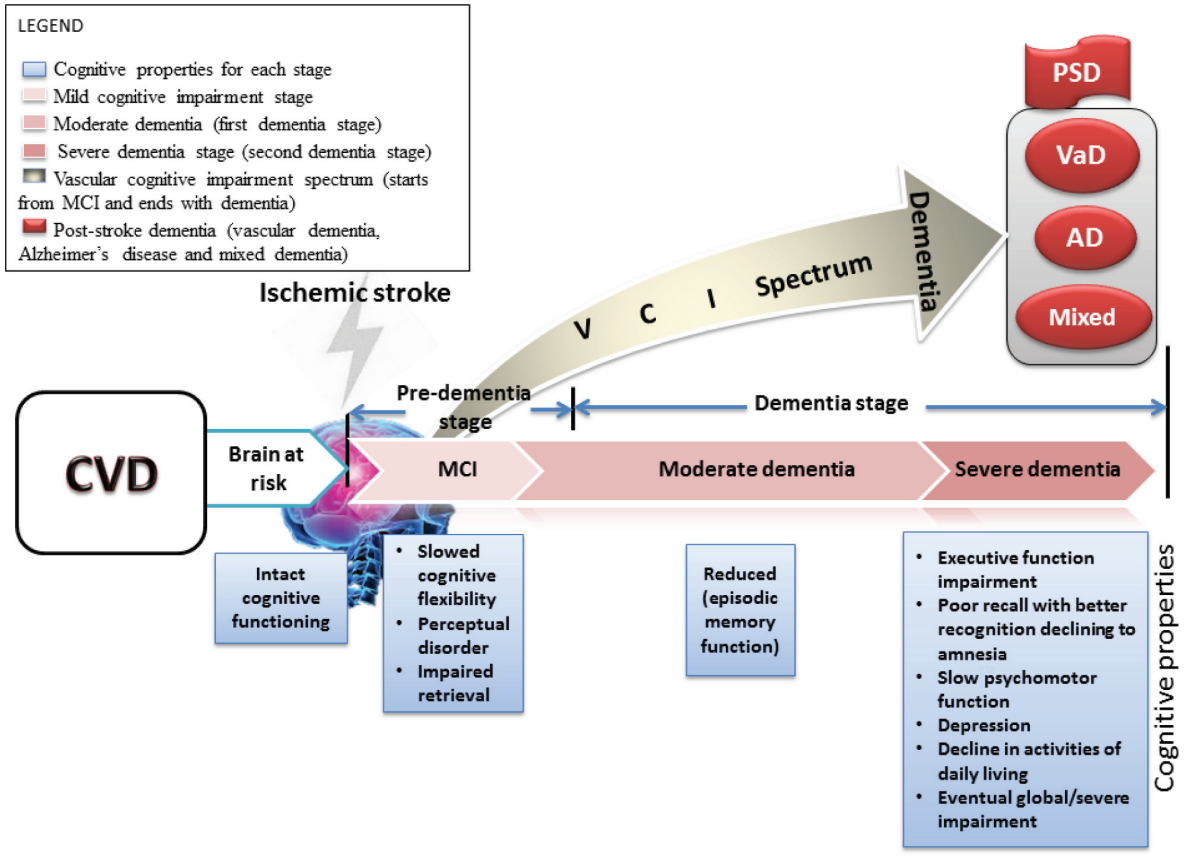

Figure 4 Block diagram of vascular cognitive impairment spectrum.
Abbreviations: AD, Alzheimer's disease; CVD, cerebral vascular disease; MCI, mild cognitive impairment; PSD, post-stroke dementia; VaD, vascular dementia; VCI, vascular cognitive impairment.

potential to develop dementia within the third month from the time dementia symptoms begin to arise.[2,20] The most observed symptoms of MCI are limited to memory, but the patient's daily living activities are preserved.[21] This article is focused on VaD as a common cause of cognitive impairment following a stroke and the effect of VaD on memory loss. It likewise discusses the available neuropsychological assessments that assess and predict the effect of dementia based on the dementia spectrum as well as aids in detecting signs of dementia, particularly memory disturbance. A number of diagnosis criteria and clinical neuropsychological assessments are combined. The most common diagnosis criteria are developed and characterized by the National Institute of Neurological Disorders and Stroke and Association Internationale pour la Recherché et l'Enseignement en Neurosciences for VaD[22–26] and Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition criteria.[27] The severity of cognitive symptoms could be assessed using the Clinical Dementia Rating Scale.[28] The most usable test to evaluate the early dementia stages, even severity of dementia in clinical practice, is the Mini-Mental State Examination (MMSE).[29]

Brain memory and causes of memory loss

The brain memory system refers to the process of how our brain transmits and stores available information for future use, with or without conscious awareness. The human brain memory system is a complex structure, with different functionalities, as shown in Table 3. Based on stroke location and severity, memory disorder may occur for one or more memory types, eventually ending in memory decline and loss.[30]

Table 3 Types of memory

Types of memory system		Anatomy (brain lobes storage)
Long-term memory	Episodic memory	Medial temporal lobe, diencephalon
	Semantic memory	Inferior and lateral temporal lobe
	Procedural memory	Basal ganglia, cerebellum
Short-term memory	Working memory	Prefrontal cortex

Table 4 Brain memory loss causes

Cause of memory loss	Subcases of memory loss	Memory loss type
Lifestyle factors	Medication	Learning
	Sleep pills, anti-histamine, anti-anxiety, schizophrenia medication, pain medication after surgery	Memory consolidation LTM
	Alcoholic and illicit drug use	Episodic memory
	Deficiency in vitamin B1, change in chemical memory	
	Stress	
	Emotional trauma (chronic or short-term stress)	
	Sleep deprivation	
	Stress, insomnia, sleep apnea	
	Nutritional deficiencies	
	Loss of vitamin B1, loss of vitamin B12	
	Marijuana consumption	
Brain injury	Acquired brain injury	LTM (episodic, semantic)
	Traumatic brain injury (assaults, road traffic accident, fall)	
	Non-traumatic brain injury	STM
	Stroke (ischemic, hemorrhagic, TIA)	Working memory
	Tumors (pediatric glial, non-glial, recurrent, metastatic, others: cysts, neurofibromatosis, pseudotumor cerebri, tuberous sclerosis)	Procedural memory
	Metabolic disorder (liver disease, kidney disease, diabetes, ischemia, oxygen hypoxia to the brain, poison through ingestion or inhalation of toxic substance)	
	Cognitive brain injury (present at birth)	
	Brain cognition (dementia), multiple sclerosis, Parkinson's disease	
Infection	HIV, tuberculosis, syphilis, herpes, encephalitis, meningitis	STM LTM
Thyroid dysfunction	Underactive, overactive	STM Working memory
Aging	Dehydration, normal aging	Recall memory Ability to think
	Depression (common with aging)	Episodic memory Procedural memory Working memory
Mild cognitive impairment	Early stage of dementia	Working memory
Dementia	AD	Episodic memory
	Cortical amyloid plaques, neurofibrillary tangles	Semantic memory
	VaD	Working memory
	Stroke, deficiencies of (thyroid hormone, vitamin B12, folic acid), hydrocephalus, hypercalcemia	LTM STM
	Mixed (AD + VaD), Lewy body disease, Parkinson's disease, frontotemporal, alcoholic	

Abbreviations: AD, Alzheimer's disease; HIV, human immunodeficiency virus; LTM, long-term memory; STM, short-term memory; TIA, transient ischemic attack; VaD, vascular dementia.

Memory loss can be caused by several factors, such as lifestyle, brain injury, infection, thyroid dysfunction, aging, MCI, and dementia (Table 4).[31]

This article focuses on stroke as the major cause of cognitive impairment resulting in memory decline. The effect of stroke varies based on its type, location, and severity.[2] After a stroke, the most prominent impairment can be recognized in the patient's processing speed, attention, and executive function. Note that 20%–50% of stroke patients suffer from memory intricacy that manifests during the period following a stroke diagnosis. PSD, particularly VaD, causes slowing in cognitive flexibility, perceptual disorder, and impairment information retrieval at the time of stroke diagnosis. This period corresponds to MCI in the VCI spectrum, followed by a decline in episodic memory function in case of dementia, and ending in severe dementia and impairment of all cognitive properties.[32–35]

Cognitive domain and memory assessment after a stroke

Cognitive impairment, particularly memory problems following a stroke, can be evaluated and assessed through neuropsychological assessments. Clinically, different neuropsychological

assessments are used to assess cognitive dysfunction in terms of cognitive domain.[36] A set of standardized neuropsychological assessments have been selected due to their sensitivity for MCI and to cover different cognitive domains including memory; for example, MMSE,[29] Montreal Cognitive Assessment (MoCA),[37] and Addenbrooke's Cognitive Examination Revised (ACE-R)[38] are widely used to assess the cognitive dysfunction of patients. Several validated clinical neuropsychological assessments are used to assess cognitive domain, including (but not limited to) Trail Making Test (TMT)[39] and Clock Drawing Test (CDT)[40] for attention and executive function (both are short tests that evaluate executive function),[18] Rey Osterrieth Figure Copy[41] for construction praxis test, and Phonological and Semantic Fluency Token test for language test.[42] Other tests (eg, Frontal Assessment Battery [FAB][43]) can be used as a quick and easy battery test. The Cambridge Examination for Mental Disorders of the Elderly,[44] is a standardized instrument that is used to investigate the cognitive domains required to diagnose dementia in multiple domains, including memory. The most common tests to assess memory

Table 5 Memory classification

Type		Test	Subtest	Brain lesion suspected location
Short-term memory		MMSE	Orientation, registration	Prefrontal cortex, Broca's area, supplementary motor cortex, left posterior parietal cortex, right posterior parietal cortex
		ACE-R	Orientation, registration	
		MoCA	Orientation	
		WMS-IV	Orientation	
		RBMT	Orientation	
Working memory		MMSE	Attention and concentration (serial subtraction), verbal (repetition of sentences), visuo-spatial (2 pentagons drawing)	Prefrontal cortex, dorsolateral prefrontal cortex
		ACE-R	Attention and concentration (serial subtraction), verbal (language repetition), visuo-spatial (2 pentagons and cube drawing), perceptual ability (dot counting and letters identifying)	
		MoCA	Attention and concentration (forward and backward list of digits), verbal (language repetition), visuo-spatial (cube drawing)	
		TMT A and B	Attention and concentration	
		Stroop test	Attention and concentration (color test)	
		WCST	Executive function	
		CDT	Visuospatial	
		WMS-IV	Visual working memory (spatial addition, spatial span)	
		WAIS-IV	Digit span (attention, concentration and mental control) Arithmetic (concentration while manipulating mental mathematical problems)	
Long-term memory	Episodic memory	MMSE	Recall three objects	Medial temporal lobe, diencephalon
		ACE-R	Recall three objects/anterograde, retrograde	
		MoCA	Delayed recall	
		WMS-IV	Delayed memory (logical memory II)	
		RBMT	Delayed recall	
	Semantic memory	MMSE	Language repetition, naming, comprehension	Inferior and lateral temporal lobe
		ACE-R	Verbal fluency, language repetition, naming, comprehension, reading, writing	
		MoCA	Verbal fluency, language repetition, naming	
		FAB	Verbal fluency	
		WMS-IV	Verbal fluency	
		RBMT	Verbal fluency	
		CVLT	Verbal fluency	
	Procedural memory	RBMT		Basal ganglia, cerebellum

Abbreviations: ACE-R, Addenbrooke's Cognitive Examination – Revised; CDT, Clock Drawing Test; CVLT, California Verbal Learning Test; FAB, Frontal Assessment Battery Scale; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; RBMT, Rivermead Behavioural Memory Test; TMT, Trail Making Test; WAIS, Wechsler Adult Intelligence Scale; WCST, Wisconsin Card Sorting Test; WMS-IV, Wechsler Memory Scale – 4th edition.

Table 6 Neuropsychological assessment characteristics

Assessments	Items	Subtests	Maximum score	Characteristics
MMSE	Orientation	Orientation to place and time	10	Time 10 minutes
	Registration	Repeat "ball, flag, tree"	3	
	Calculation/ WORLD	Serial 7 subtraction/WORLD backward	5	
	Memory recall	Recall "ball, flag, tree"	3	
	Language naming	Name of two objects (a watch and a pen)	2	
	Language comprehension	"Close your eyes," "Pick up the paper in your right hand, fold it in half, and set it on the floor"	3	
	Language writing	Write a sentence	1	
	Language repetition	Repeat "No ifs, ands, or buts"	1	
	Visuo-spatial abilities	Draw two pentagons	1	
	MMSE total score		30	
ACE-R	Orientation*	Orientation to place and time	10	Time 15–20 minutes
	Registration*	Repeat "lemon, key, ball"	3	
	Calculation/ WORLD*	Serial 7 subtraction/WORLD backward	5	
	Recall*	Recall "apple, table, penny"	3	
	Anterograde	Repeat name and address, best of three trials	7	
	Retrograde memory	Current prime minister, last prime minister, current US president, last US president	4	
	Letter fluency**	No of words in 1 minute	7	
	Category fluency	No of animals in 1 minute	7	
	Comprehension*	Obey written instruction "close your eyes," perform three-step command	4	
	Writing*	Write a sentence	1	
	Repetition*	Repeat "hippopotamus, eccentricity, unintelligible, statistician," "above, beyond, and below," and "no ifs, ands, or buts"	4	
	Naming*	Confrontation naming (12 line drawings)	12	
	Picture comprehension	For example, "point to the object with a nautical connection"	4	
	Reading	Read list of five words	1	
	Visuoexecutive*	Intersecting pentagons, cube, and clock drawing	8	
	Visuoperceptual	Dot counting without pointing, recognition of fragmented letters	8	
	Address recall	Recall of name and address learned earlier	7	
	Address recognition	Recognition of name and address items (if not recalled spontaneously)	5	
	ACE-R total score		100	
MoCA	Visuoexecutive*	Trail B test, cube copy, clock drawing	5	Time 10–15 minutes
	Naming*	Confrontation naming (lion, hippo, camel)	3	

(*Continued*)

Table 6 (*Continued*)

Assessments	Items	Subtests	Maximum score	Characteristics
	Digit span	Forward (five digits), backward (three digits)	2	
	Attention	Tapping at the letter A in letter list	1	
	Calculation*	Serial 7 subtractions	3	
	Repetition*	Repetition of two complex sentences	2	
	Verbal fluency**	>11 words beginning with the letter F in 1 minute	1	
	Abstraction	Similarities (eg, train and bicycle = transport)	2	
	Recall*	Recall a list of five words	5	
	Orientation*	Date, month, year, day, place, city	6	
	MoCA total score		30	
FAB	Similarities	Conceptualization	3	Time 10–15 minutes
	Lexical fluency**	Mental flexibility	3	
	Motor series	Programming	3	
	Conflicting instructions	Sensitivity to interference	3	
	Go-No-Go	Inhibitory control	3	
	Prehension behavior	Environmental autonomy	3	
	FAB total score		18	

Notes: *ACE-R and MoCA contain MMSE items; **MoCA and FAB same item.
Abbreviations: ACE-R, Addenbrooke's Cognitive Examination – Revised; FAB, Frontal Assessment Battery Scale; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment.

evaluate memory in terms of retention, retrieval, and encoding (eg, the Wechsler Memory Scale (WMS)-Revised[45] may be employed to distinguish amnesia from dementia in patients). For verbal memory, numerous assessments are used, including the WMS,[46] Rey Auditory Verbal Learning Test,[47] Rivermead Behavioral Memory Test (RBMT),[48] and California Verbal Learning Test.[48] Memory disorder in elderly dementia patients can be assessed using the Free and Cued Selective Reminding Test. This test aids in distinguishing dementia from normal aging with acceptable accuracy.[36]

Until recently, no specific assessment was developed specifically to assess short-term memory, working memory, and long-term memory impairment following stroke VaD. Thus, evaluating memory in terms of its types to predict stroke effect on memory retrieval is important.

PSMA

The decline in memory as a result of stroke VaD and the characterization of memory complaint based on VaD development can be assessed through a PSMA. This assessment is based on the most popular studies and is a combination of available neuropsychological assessment tests.[49,50] Memory evaluation is proposed to be associated with memory types. Thus, short-term memory and working memory refer to the perceptual and learning areas of the cognitive domain, which are processed by the frontal lobe. Episodic and semantic long-term memory refers to memory, language, and visuospatial domains, which are processed by the parietal, medial temporal lobe, and hippocampus. Procedural memory refers to the procedural domain and is processed by the cerebellum and basil ganglia. Table 5 describes the proposed PSMA, which achieves this demand. The concept integrated the most usable neuropsychological assessments (MMSE, ACE-R, MoCA, WMS-IV, RBMT, TMT A and B, CDT, FAB, Wechsler Adult Intelligence Scale – Fourth Edition, and others) and reconstructed them to evaluate memory types.[50]

PSMA was designed with inspected administration time of 30 minutes, as illustrated in the Supplementary materials. The test examines the following:

- Orientation: in time and place
- Short-term memory: a seven-digit number, phone number, and postal code
- Working memory: attention and concentration, verbal working memory, and visuospatial working memory
- Explicit long-term memory: episodic memory and semantic memory
- Procedural memory.

Discussion

Neuropsychological assessments are used in evaluating and assessing cognitive impairment and dementia. Specific assessment is urgently needed to evaluate different types of memory functionalities after stroke. The present study focused on using available neuropsychological assessments to develop a PSMA scheme based on scientific knowledge, which is available through neuropsychological testing. PSMA may help provide impetus to detect the earliest stages of dementia before significant mental decline. Therefore, efforts are being exerted to use more than one assessment to evaluate cognitive impairment and memory dysfunction. For instance, the MMSE is a brief test with extensive international usage; however, several studies have mentioned that the MMSE alone can be used in a sensitive test to detect cognitive impairment, except if cutoff is increased or combined with other neuropsychological tests.[51,52] Therefore, the MMSE was used with MoCA and ACE-R to detect MCI because the last two assessments are used to assess early stages of dementia and executive function, as well as identify frontal subcortical infarction.[50,53,54] In addition, ACE-R has good sensitivity for dementia, whereas MoCA is specifically used in MCI screening. Moreover, TMT, Stroop, and CDT tests can be used with the MMSE to evaluate frontal lesion verbal fluency, and visuospatial skills can be evaluated through Rey Osterrieth figure recall. FAB has been reported to identify frontal temporal lobe dysfunction.[55] MMSE, ACE-R, MoCA, and FAB characteristics are shown in Table 6. It can be noticed from the table that the administration time ranged from 35–45 minutes for four assessments. The PSMA administration time was reduced approximately to 30 minutes. PSMA has been designed to incorporate more than one neuropsychological assessment to evaluate short-term, working, and long-term memory with less time consumed compared with multiple test usage. Using more than one assessment to evaluate patient mentality takes a longer time, resulting in patient difficulty in concentrating on the assessment items. PSMA evaluates the cognitive domain and focuses on memory types that are affected by VaD.

Conclusion

Currently, no specific neuropsychological assessment to assess memory in terms of its types exists. This article provides an overview of the effects of stroke on the brain and on cognitive impairment, including memory evaluation with the most commonly used neuropsychological tests. The article proposes a PSMA to assess different types of memory based on the available assessments. It likewise uses the widely available neuropsychological assessments to study the association between memory as a part of cognitive domain and cognitive impairment, which lead to memory decline in the period following stroke onset.

Disclosure

The authors declare that there are no conflicts of interest in this work.

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Supplementary materials

Post-stroke memory assessment	
Name:	**Date of test:**
Sex:	**Date of stroke diagnosis:**
Handedness:	**Site of stroke:**
Date of birth:	**Type of stroke:**
Education:	**Tester's name:**
Occupation:	
Nationality:	**Level of education:**

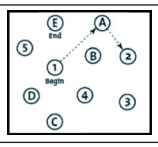
	Did not go to school		Primary education
	Secondary education		Diploma
	Degree		Post graduate

Orientation:						**Note:** The score is added to short-term memory.
What is the:	AM/PM	Day	Date	Month	Year	/5
Which:	Building	Floor	Town	State	Country	/5

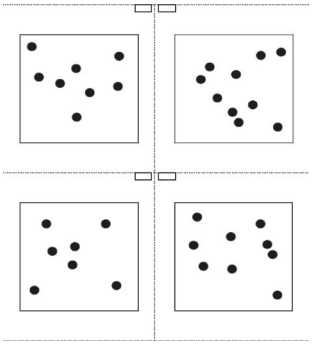
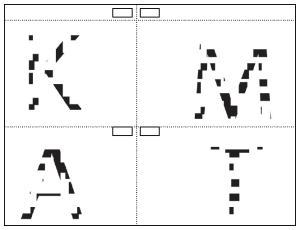
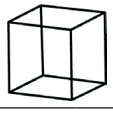
1. Short-term memory:	**Total score:**	**/20**
i. Registration:		**/7**
I am going to read a list of 7 words. I want you to repeat after me:		
Ball, Flag, Tree, Yellow, Apple, Tiger, Office		

ii. 7 digits number:	**/1**
I am going to say a series of numbers for you to remember. When I am finished, I want you to select which group I said: 7 digits number: 8-6-0-2-9-1-7	
1. 8-6-0-5-9-1-7	
2. 8-0-6-2-4-1-7	
3. 8-6-0-2-9-1-7	
4. 8-6-2-0-4-1-7	
5. 8-6-0-5-4-1-7	
6. 8-0-6-2-9-1-7	

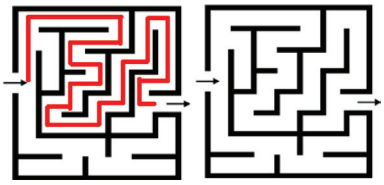
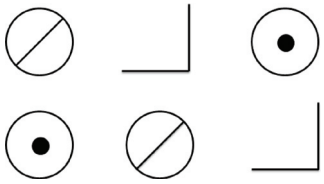
iii. The phone number and postal code:	**/2**
I am going to say a phone number and postal code for you to remember. When I am finished, I want you to repeat what I said: Postal code: 00964 The phone number is: 5463279	

2. Working memory:	**Total score:**	**/30**
A. Attention and concentration:		**/10**
i. Number forward		**/1**
I am going to read a list of 5 numbers. I want you to repeat them in the forward order. **2-1-8-5-4**		
ii. Number backward		**/1**
I am going to read a list of 3 numbers. I want you to repeat them in the backward order. **7-4-2**		
iii. Serial subtraction		**/3**
Serial 7 subtractions are starting at 100.		
[ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65 [ ] 58 [ ] 51		
Notes: 4 or 5 correct subtractions: 3 pts, 2 or 3 correct: 2 pts, 1 correct: 1 pt, 0 correct: 0 pt.		
iv. Alternating trail making		**/1**
Join the following circles as in the example.		
		

(*Continued*)

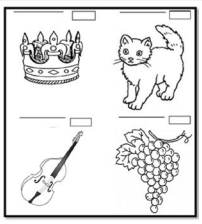
v. Color test:	**/2**
I am going to show you a list of color words that are printed in ink colors unrelated to the printed words. I want you to name the color of the printed word not to read the word.	
	
vi. Perceptual abilities (A):	**/1**
– I am going to show you a square of stars; I want you to count the stars group that I am pointing.	
	
vii. Perceptual abilities (B):	**/1**
– I am going to show you a group of letters. I want you to identify the letters.	
	
B. Verbal working memory:	**/10**
i. Memory of sentences:	**/2**
I am going to read a sentence; I want you to repeat it.	
The boy rode a horse at the zoo	
ii. Memory of stories:	**/2**
I am going to read a story. I want you to retell as much of the story as possible.	
The Bank Robbery Three armed men burst through the doors of the bank at Hillstone on Tuesday afternoon, just after half past two. They ordered a frightened 19-year-old teller to fill the six large, red suitcases they carried with money. When the bags were filled, the three men ran to a green, late-model station wagon and drove off along Mark Street.	
iii. Reading span:	**/2**
You will read a series of sentences and then, sequentially, I want you recall the final word in each sentence.	
1. The pencil is above the flower **2. The teacher will read the story after lunch**	
iv. Listening span:	**/2**
I am going to read a series of sentences and then you will recall the final word of each sentence.	
1. My friend got a rabbit for her birthday **2. The cup is in the box**	
v. Operation span:	**/2**
I am going to show you a simple math problem you try to solve it:	
(12÷2)–4=?	
C. Visuospatial working memory:	**/10**
i. Cube:	**/1**
I am going to show you a cube; I want you to copy the diagram.	
	

(*Continued*)

ii. Clock:	**/5**
Ask the subject to draw clock (Ten past eleven)	
[ ] counter [ ] number [ ] hands	
iii. Mazes memory:	**/1**
I am going to show you a maze. I want you to follow the red line in the maze with your finger and then draw the exact route that was just observed on an identical, but empty, maze.	
	
iv. Visual recognition cards:	**/3**
I am going to show you three cards in two lines, I want you to join the same cards together.	
	

3. Explicit long-term memory:	**Total score: /40**

A. Episodic memory:				**Total score:**	**/15**
i. Recall:					/5
Tell me what you remembered of the 5 words I mentioned at the beginning.					
ii. Anterograde memory:					/5
Fill in the blanks the hospital address					
	Building	***Floor***	***Town***	***State***	***Country***
iii. Retrograde memory:					/5
• Name of current Malaysia's prime minister					
• Name of the capital of Malaysia					
• Name of current USA president					
• Name of first Malaysia's prime minster					
• Date of the Malaysia's national day					

B. Semantic memory:	**Total score: /20**
i. Verbal fluency (lexical fluency)	**/4**
Name maximum numbers of words in one minute that are begin with the letter F.	
Note: N ≥11 words.	
ii. Language	**/6**
1. Repetition:	**/2**
Repeat:	
I only know that John is the one to help today.	
The cat always hid under the couch when dogs were in the room.	
2. Naming	**/4**
Ask the subject the name of the following pictures:	
	
3. Comprehension:	**/4**
Using the picture above, ask the subject to:	
– Point to the one associate to the monarchy	

(*Continued*)

– Point to the one which is a mammal – Point to the one which is a musical instrument – Point to the one which is a fruit	
4. Reading:	**/2**
Ask the subject to read the following words: **Sew, Pint, Soot, Height**	
5. Writing:	**/4**
I am going to read words; I want you to write the following: **Blue, England, Yellow, Italy**	

4. Procedural memory:	**Total score: /10**
Ask the subject to:	
• Dial a phone number	
• Fold the paper into two sides	

Delayed recall episodic memory:	**Total score: /5**
Ask "Now tell me what you remember of the 5 words I mentioned at the beginning".	

		Sub scores	Total scores
Short-term memory	**Orientation**	**/10**	**/20**
	Registration	**/7**	
	7 digits number	**/1**	
	Phone no and postal code	**/2**	
Working memory	**Attention and concentration**	**/10**	**/30**
	Verbal WM	**/10**	
	Visuospatial WM	**/10**	
Long-term memory	**Episodic memory**	**/15**	**/35**
	Semantic memory	**/20**	
Procedural memory	**Dial a phone number**	**/5**	**/10**
	Fold the paper into two sides	**/5**	
Episodic	**Delay recall**	**/5**	**/5**