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

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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.
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                                                                      | Subarachnoid                                                                                             |
|                                                                                                | Attacks resulting from the temporary interruption of blood flow to the parts of the brain.                |
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. 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. 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).

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. 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. 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.”

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. 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

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**Figure 1** Risk factors and dementia.

**Figure 2** Clinical evaluation.

**Abbreviations:** CT, computed tomography; ECG, electrocardiography; EEG, electroencephalography; MRI, magnetic resonance imaging.
Figure 3 Core and penumbra after stroke.

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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, Apraxia, Language usage (pragmatic language), Disorders, Anosognosia, Anosodiaphoria |
| Posterior cerebral artery | Color agnosia, Associative visual agnosia, Alexia (hemianopic and pure), Facial agnosia, Bälint’s syndrome, Amnesia |
| Anterior cerebral artery | Deficits in planning, initiation, monitoring, concentration, and flexibility, Contralateral leg weakness, Sensory loss, Impaired arousal, attention, motivation, initiation, and executive function, Memory (verbal, visual, episodic declarative, anterograde, and retrograde), Impaired problem solving and attention, Memory |
| Subcortical infarcts (include thalamic infarcts) | Confusion, Memory disturbance, Amnesia, Personality changes, Confabulation, Abulia due to damage to the mesial frontal cortex |
| Caudate infarcts | Implicated in a failure to learn and retain new information, Affective changes |
| Limbic and paralimbic lesion | |
potential to develop dementia within the third month from the time dementia symptoms begin to arise.\textsuperscript{2,20} The most observed symptoms of MCI are limited to memory, but the patient’s daily living activities are preserved.\textsuperscript{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 Recherche et l’Enseignement en Neurosciences for VaD\textsuperscript{22–26} and Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition criteria.\textsuperscript{27} The severity of cognitive symptoms could be assessed using the Clinical Dementia Rating Scale.\textsuperscript{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).\textsuperscript{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.\textsuperscript{30}

**Table 3 Types of memory**

| Types of memory system | Anatomy (brain lobes storage) |
|------------------------|-------------------------------|
| Long-term memory       | Episodic memory               |
|                         | Semantic memory               |
|                         | Procedural memory             |
|                         | Working memory                |
| Short-term memory       | Medial temporal lobe,         |
|                         | diencephalon                  |
|                         | Inferior and lateral          |
|                         | temporal lobe                 |
|                         | Basal ganglia, cerebellum     |
|                         | Prefrontal cortex             |
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. 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, Montreal Cognitive Assessment (MoCA), and Addenbrooke’s Cognitive Examination Revised (ACE-R) 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) and Clock Drawing Test (CDT) for attention and executive function (both are short tests that evaluate executive function), Rey Osterrieth Figure Copy for construction praxis test, and Phonological and Semantic Fluency Token test for language test. Other tests (eg, Frontal Assessment Battery [FAB]) can be used as a quick and easy battery test. The Cambridge Examination for Mental Disorders of the Elderly, 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    |
|                       | ACE-R      | Orientation, registration                              | motor cortex, left posterior parietal cortex,     |
|                       | MoCA       | Orientation                                             | right posterior parietal cortex                   |
|                       | 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 (serial subtraction)       |                                                   |
|                       | Stroop test| Attention and concentration (color test)               |                                                   |
|                       | WCST       | Executive function                                      |                                                   |
|                       | CDT        | Visuospatial                                            |                                                   |
|                       | WMS-IV     | Visual working memory (spatial addition, spatial span) |                                                   |
|                       | WAIS-IV    | Arithmetic (concentration while manipulating mental mathematical problems) |                                                   |
| Long-term memory      | MMSE       | Recall three objects                                    | Medial temporal lobe, diencephalon                |
| Episodic memory       | 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       | Verbal fluency                                          | 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 memory | 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                                 | 3             | Time 10–15 minutes |
|               |                        | Conceptualization                            |               |                 |
|               |                        | Mental flexibility                            | 3             |                 |
|               |                        | Programming                                  | 3             |                 |
|               |                        | Sensitivity to interference                  | 3             |                 |
|               |                        | Inhibitory control                           | 3             |                 |
|               |                        | 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 may be employed to distinguish amnesia from dementia in patients). For verbal memory, numerous assessments are used, including the WMS, Rey Auditory Verbal Learning Test, Rivermead Behavioral Memory Test (RBMT), and California Verbal Learning Test. 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.

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. 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 basal 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.

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.\(^{31,53}\) 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: | Level of education: |
| Nationality: | Did not go to school |
| | Primary education |
| | Secondary education |
| | Diploma |
| | Degree |
| | Post graduate |

Orientation:

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

1. Short-term memory:

i. Registration:

| Total score: | /20 |
|--------------|-----|
| 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:

| Total score: | /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:

| Total score: | /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:

A. Attention and concentration:

i. Number forward

| Total score: | /10 |
|--------------|-----|
| 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

| Total score: | /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

| Total score: | /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

| Total score: | /1 |
|--------------|----|
| Join the following circles as in the example. |

(Continued)
v. Color test:  
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.

Red  Blue
Green  Yellow

vi. Perceptual abilities (A):  
– 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):  
– I am going to show you a group of letters. I want you to identify the letters.

B. Verbal working memory:  
1. Memory of sentences:  
I am going to read a sentence; I want you to repeat it.

The boy rode a horse at the zoo

2. Memory of stories:  
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.

3. Reading span:  
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

4. Listening span:  
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

5. Operation span:  
I am going to show you a simple math problem you try to solve it:

\[(12 ÷ 2) - 4 = ?\]

C. Visuospatial working memory:  
1. Cube:  
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.

![Maze Diagram]

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.

![Visual Recognition Cards]

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 minister
   • 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:

   ![Language 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: /10
Ask the subject to:
• Dial a phone number
• Fold the paper into two sides

Delayed recall episodic memory: /5
Ask “Now tell me what you remember of the 5 words I mentioned at the beginning”.

| Sub scores | Total scores |
|------------|-------------|
| Orientation | 10          |
| Registration| 7           |
| 7 digits number | 1     |
| Phone no and postal code | 2     |
| Attention and concentration | 10  |
| Verbal WM | 10          |
| Visuospatial WM | 10    |
| Episodic memory | 15  |
| Semantic memory | 20    |
| Dial a phone number | 5     |
| Fold the paper into two sides | 5     |
| Delay recall | 5   |

Cognitive impairment and memory dysfunction after a stroke

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