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A systematic review of fMRI studies of healthy adult human brain activation on learning and memory patterns for numerals

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Abstract: This systematic review examines the empirical evidence from previous fMRI studies on brain activation areas for learning and memory patterns for numerals to understand the question of the brain activation areas found from previous fMRI studies on learning and memory patterns for numerals. Relevant articles in the fields of psychology, neuroscience, paediatrics, and education were extracted from the PubMed database. Keyword searches included "learning", "memory", "brain", "digits", "numerals", and "fMRI". The database search was conducted from July 2022 to August 2022. The data collected was limited to English texts, and studies involving animal experiments were excluded. The remaining articles were screened based on the inclusion and exclusion criteria. Articles included in this review were selected from the database search between 1999 to 2022. Ten full-text articles were identified and evaluated. Examination of brain activation regions in learning and memory patterns for numerals revealed that 30% of studies (n=3) found activation in the hippocampus, inferior parietal lobe and parietal lobe. Subsequently, 20% of the studies (n=2) found activation in the anterior cingulate, caudate nucleus, cerebellum, frontal lobe, inferior frontal gyrus, inferior temporal gyrus, medial temporal lobe, occipital lobe, prefrontal cortex, striatum, and thalamus. The frontoparietal network is considered important for working memory, while the limbic areas are essential for learning and memory. Therefore, future studies should look more closely at the brain's functional and structural regions involved in learning and a more specific memory system.

Keywords: Learning; memory; numerals; digits; fMRI

1.0 INTRODUCTION

Learning is a crucial ability of the human brain for survival, and memory plays an essential role in the learning process (Atkinson and Shiffrin, 1968; Johnson, 1994; Loaiza et al., 2021). According to de Houwer and colleagues (2013), learning can be defined as the changes in an organism's behaviour that result from regularities in the organism's environment. However, Ginsburg and Jablonka (2021) describe that learning requires a sensory stimulus, either from the system's activities or from the external biotic or abiotic world, that leads to a change in the internal state of the system when the stimulus is encoded. Thus, to learn new information, memory systems play an important role (Atkinson and Shiffrin, 1968; Loaiza et al., 2021). To illustrate these memory systems, in simple cognitive tasks such as calculation, short-term memory (STM) will engage to hold the individual digits and their position in the number (Atkinson and Shiffrin, 1968; Loaiza et al., 2021). Working memory (WM) retrieves the arithmetic knowledge to be applied to these numbers from long-term memory (LTM) to make changes to these series of numbers in a specific order (Berg, 2008). Zhang and Norman (1995) showed that digits have many levels of representation because digits are unique and flexible. They can be used for counting objects or items, telling the time, calculating prices, recognising telephone numbers, keeping scores of games, and many more. They also consented that the digits in numbers derive from languages that involve complex representational systems in different brain regions (Zhang and Norman, 1995).

Functional magnetic resonance imaging (fMRI) with a contrast agent called blood-oxygenation-level-dependant (BOLD) can provide images to identify brain activation regions using at least one multivariate statistical analysis. This modality is non-invasive and does not require ionising radiation to acquire rich functional data (Boly et al., 2015). According to researchers, the brain regions involved in learning and memory are the hippocampus (Nie et al., 2019; Schendan et al., 2003; Shum et al., 2013), the inferior parietal lobe (Munk et al., 2002; Schmithorst and Brown, 2004; Yi et al., 2009), and the parietal lobe (Lycke et al., 2008; Munk et al., 2002; Nie et al., 2019). This systematic review will examine the evidence from previous fMRI studies on how learning and memory patterns for numerals affect different brain parts. The research question will be what are the brain activation areas found in previous fMRI studies on learning and memory patterns for numerals? This review hypothesises that there will be brain activation in the parietal lobe for memory and prefrontal networks for learning.

2.0 SEARCH STRATEGY

The data collected in the current review were obtained from the PubMed database, which was searched from July 2022 to August 2022. Relevant articles were selected from psychology, neuroscience, paediatrics, and education. The keywords and Boolean search terms are used: (learning OR memory) AND brain AND (digits OR numerals) AND fMRI. The current review was screened by title and abstract, sample and methods, and irrelevant entries were excluded. The remaining articles were reviewed based on the inclusion and exclusion criteria of the current study. The articles in this review were published between 1999 to 2022. **Figure 1** shows the process of the study selection based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flowchart (Moher et al., 2009).

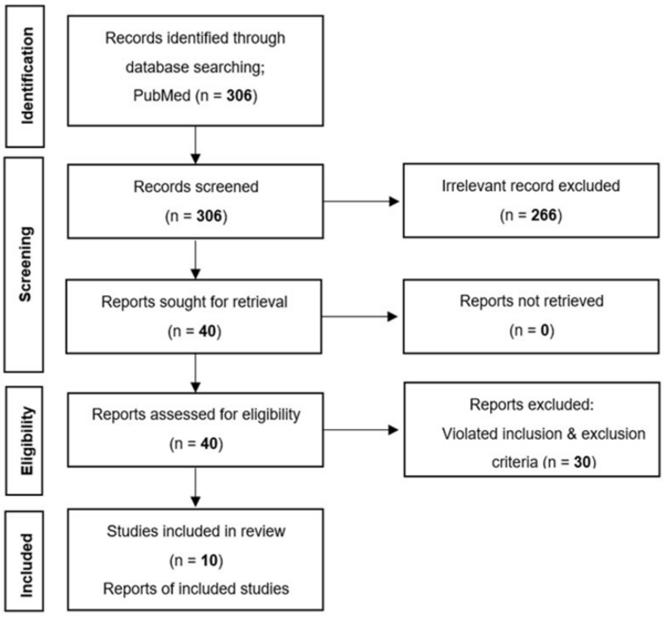

Figure 1. Flow chart of the literature extraction and screening process. Of the 306 articles extracted, 296 were removed, and ten were selected.

Articles were selected based on the following inclusion criteria: 1) healthy individuals aged 18 to 40 years, 2) studies conducted in any country with participants of any language background, 3) use of fMRI technique with any task involving words, numerals, or digits, 4) publication in English and 5) open access and full-text articles. Exclusion criteria: 1) animal studies and 2) review articles and opinions.

3.0 SEARCH RESULTS

A total of 306 articles were identified in the PubMed database using a keyword search. Two hundred sixty-six articles were excluded because they were irrelevant according to the above eligibility criteria. Consequently, 40 abstract full-text articles were evaluated, and only ten full-text articles met the eligibility criteria. **Table 1** has a list of the articles or studies that were used for this review.

Table 1. Information of articles included in the review

Reference	Title	Type of Task
Pinel et al., 1999	• Event-related FMRI analysis of the cerebral circuit for number comparison	• Random letter string & Numerical memory task
Munk et al., 2002	• Distributed cortical systems in visual short-term memory revealed by event-related functional magnetic resonance imaging	• Visual stimuli (fruit drawings & position of images) memory task
Schendan et al., 2003	• An fMRI study of the role of the medial temporal lobe in implicit and explicit sequence learning	• Numerical sequence memory task
Walter et al., 2003	• Special Issue evidence for quantitative domain dominance for verbal and spatial working memory	• N-back letter, numeral, positioning memory task
Schmithorst et al., 2004	• Empirical validation of the triple-code model of numerical processing for complex math operations using functional MRI and group Independent Component Analysis of the mental addition and subtraction of fractions	• Numeral fraction problem task
Lycke et al., 2008	• An fMRI study of phonological and spatial working memory using identical stimuli	• Phonological with non-words (consonant-vowel-consonant) and positioning working memory task
Huijbers et al., 2009	• When learning and remembering compete: A functional MRI study	• Word retrieval and scene encoding task
Yi et al., 2009	• Behavioural and Neural Correlates of Memory Selection and Interference Resolution during a Digit Working Memory Task	• Numeral Recognition task
Shum et al., 2013	• A brain area for visual numerals	• Numeral Memory task
Nie et al.,2019	• Different memory patterns of digits: A functional MRI study	• Numeral Memory task

4.0 BRAIN DEVELOPMENT

Human brain development begins in the prenatal period when the five senses (i.e., smell, touch, taste, vision, hearing) are developed, and prenatal sensory experiences contribute to shaping the brain (Budday et al., 2015; Borsani et al., 2019). From 0 to 10 months of age, significant wiring of neurons occurs, and greater activation is seen in the frontal lobes of the brain (Beason-held and Horwitz, 2002; Bear et al., 2007; Stiles et al., 2015). Between the ages of 3 and 6, 100 trillion synapses have been formed, and by the age of 6, the brain has reached 95% of adult weight and energy consumption peaks (Beason-held and Horwitz, 2002; Bear et al., 2007; Stiles et al., 2015). Between the ages of 7 and 22, the prefrontal cortex is the last to mature, and during this phase, the white matter increases while the grey matter is still regressing, and there are now 500 trillion synapses (Beason-held and Horwitz, 2002; Bear et al., 2007; Stiles et al., 2015). In the phase from 23 to 65 years, the brain reaches its maximum capacity at age 22, and as we age, memory capacity declines, and processing speed decreases (Beason-held and Horwitz, 2002; Bear et al., 2007; Stiles et al., 2015). In the later stages of 65 years and older, brain cells in critical areas of the brain begin to be absent and hippocampal function declines (Beason-held and Horwitz, 2002; Bear et al., 2007; Stiles et al., 2015). Furthermore, Archer and colleagues (2018) found that age is associated with a linear decline in brain activation during spatial working memory performance.

Johnson et al. (2018) found that prefrontal cortex activity supports memory formation in the developing brains of subjects aged 6.2 to 19.4 years. They found that early prefrontal cortex activity predicted better accuracy and that variations of duration (e.g., sub-second deviations) in activity flow between subregions predicted memory formation (Johnson et al., 2018; Borsani et al., 2019). In addition, the flow of activity between inferior and precentral areas was refined in adolescence, which explained the improvement in memory performance. In a different light, mean frontal activity predicted memory regardless of age (Johnson et al., 2018). Their study showed how vital the prefrontal cortex is for memory development (Johnson et al., 2018).

Meanwhile, Tang and colleagues (2018) observed different prefrontal cortex regions to have other involvement in supporting memory formation in the participants aged between 8 and 25 years old. The lateral prefrontal cortex showed subsequent positive memory (e.g., visual scenes), and the superior and medial prefrontal cortex negatively affected subsequent memory, and these effects increase with age. Moreover, they found that the functional connectivity in the lateral prefrontal cortex and regions in the medial temporal lobe increased with age during memory formation. In contrast, the functional connectivity in the superior prefrontal cortex and medial temporal lobe regions decreased with age. These results are consistent with the findings by Yue et al. (2017), whereby they found that the middle areas of the brain, including the hippocampus and medial temporal lobe, are related to memory.

5.0 LEARNING AND MEMORY

Learning includes or enables all the properties identified as cognitive capacities or mechanisms. Therefore, any system that can learn is cognitive and is defined as a process that leads to an experience-dependent behavioural response system (Ginsburg and Jablonka, 2021). Ginsburg and Jablonka (2021) suggest that learning requires a sensory stimulus that originates from either 1) the activities of the system or 2) the external biotic, or 3) the abiotic world and results in a change in the internal state of the system when the stimulus is encoded. This change is remembered (storage), which requires active stability and valence mechanisms of positive or negative reinforcement (Ginsburg and Jablonka, 2021). The behavioural response threshold changes due to further interactions with the stimulus or related stimuli (recall or retrieval) (Ginsburg and Jablonka, 2021). Learning involves sensor–effector connection, valence attribution (intrinsic reinforcement), storage, and retrieval (Ginsburg and Jablonka, 2021). The learning process involves changes in response threshold so that the system can be expected to 'predict' the effects of the learned stimuli (Ginsburg and Jablonka, 2021). This process allows for complicated decision-making and is based on an individual's lifetime experience that influences changes in response thresholds when a biological system produces the signal (e.g., social learning; communication). Thus, a learning system includes some explicit associations of learning with cognition, intelligence, or mind and is, therefore, a cognitive system (Ginsburg and Jablonka, 2021). As humans evolve, they must learn new information to adapt and survive. Learning can be defined as the changes in an organism's behaviour resulting from regularities in the environment (de Houwer et al., 2013). To learn something, when a stimulus is presented, there is an immediate registration of that stimulus on the appropriate sensory dimensions (e.g., visual stimuli on the visual sensory) (Atkinson and Shiffrin, 1968; Loaiza et al., 2021; Stiles et al., 2015). Then, the information is temporarily stored for later processing in the STM and WM systems. At this stage, the data is either degraded or stored in the LTM for later use (Atkinson and Shiffrin, 1968; Loaiza et al., 2021; Stiles et al., 2015).

From a different perspective, John Sweller (1988), in Cognitive Load Theory (CLT), describes how the human brain takes in processes, retains, and comprehends essential information. WM combines the intrinsic ability of the brain to integrate sensory data and communicate with LTM consciously. This WM has a temporal capacity of 5 to 9 seconds and aids comprehension by processing the new influx of information from sensory registers (Chen et al., 2018). Information comprehension is impaired when the WM is overloaded with complex data, which is called Cognitive Loads (CLs), which mainly have three types: intrinsic cognitive (ICL), extraneous cognitive load (ECL), and Germane load (GL). An example of how to efficiently learn new information is the dual-coding theory, which states that learners process new information best when they use both auditory and visual modalities, as this helps to reduce CLs (Mousavi et al., 1995). Thus, CLT explains how a learner can improve learning by manipulating CLs to help transform information into LTM (Fraser et al., 2018).

Memory is a complex process in which memory processes in the human brain include the following stages: processing, storage, and retrieval of information for later use (Stiles et al., 2015). Khan and colleagues (2020) describe memory as modifying behaviour based on reusing past experiences. In other words, memory is also defined as the ability to acquire (encode), retain (store), and retrieve (recall) information (Khan et al., 2020). But memorisation means something different. It is the learning process in which a person has understood a concept and can remember it forever and bring it back to mind when needed (Loaiza et al., 2021; Spear and Riccio., 1994; Stiles et al., 2015).

According to previous literature, memory is divided into three subcategories: LTM, STM, and WM (Atkinson and Shiffrin, 1968; Cowan, 2009; Stiles et al., 2015). Cowan (2009) noted that previous theoretical perspectives have a common recognition of the term LTM, which can be defined as the comprehensive storage of knowledge and record of past events. LTM can hold an indefinite amount of information (Cowan, 2015; Loaiza et al., 2021; Stiles et al., 2015). In contrast, STM includes the ability to hold limited information temporarily in a retrievable state, typically around 30 seconds (Cascella and Al Khalili, 2021; Cowan, 2015). As defined by Miller et al. (1960), MW is the memory used to plan and execute behaviours. Cascella and Al Khalili (2021) further summarise that WM is a set of processes involving the functional memory element of the STM. According to a model of WM by Baddeley (1986), the components of working memory consist of several processes involving verbal-phonological and visuospatial representation. To manage and modify these processes, attention-related processes called "central executive" take place. Furthermore, Baddeley (2000) added an "episodic buffer" to the WM model, the central executive memory, which spans the representational domains. In short, WM combines different components to organise and divide the information into smaller units (Baddeley, 2000).

To investigate the capacity of memory systems, simple memory span tasks have been used in research for STM and complex memory span tasks for WM (Manoochehri, 2021). Memory span is the ability of an individual to recall a series of discrete stimuli in their original order after only one presentation (Manoochehri, 2021). Miller's (1956) pioneering work, identifying the magic number seven as the capacity of STM, was based on the results of simple span exercises. To examine the capacity of WM, it is helpful to summarise the results of the few accessible studies from a comparative perspective. Read (2008) concluded in one such experiment that the capacity of WM in chimpanzees (possibly the greatest or equally highest among primates) is only about two items. Carruthers (2013), on the other hand, claims that the limits of WM are within the human range, at least in some monkey species. Both studies agree that human WM has a capacity of three to four items. Gignac (2015) indicated a significant difference between STM and WM, with the mean score of STM in adults estimated to be 6.56 (±2.39) and the mean score of WM in adults estimated to be 4.88 (±2.58). WM was also found to have a lower capacity than STM, as a compilation of studies by Cowan suggests that WM has a capacity of 4 (±1) (Cowan, 2001; Cowan, 2010). Based on previous literature, the current review uses studies involving procedures with memory span tasks or similar tasks. The summary of memory systems obtained of earlier studies is shown in **Figure 2**.

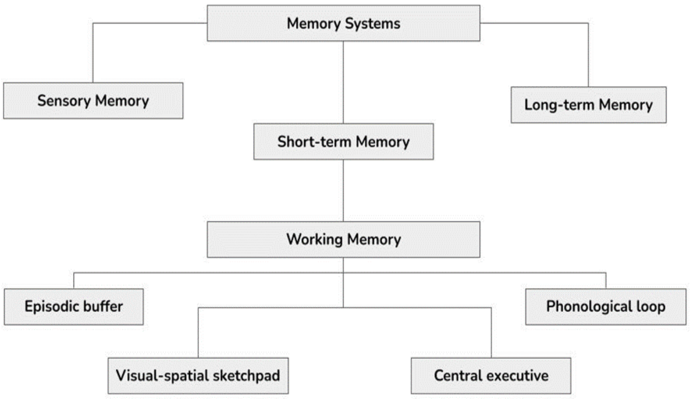

Figure 2. Summary of memory systems adapted from previous literature.

6.0 NEUROIMAGING TOOLS

To determine the functions and location of brain regions, various functional neuroimaging techniques can be used, such as positron emission tomography (PET), single-photon emission tomography (SPECT), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), event-related potentials (ERPs), electrocorticography (ECoG), magnetoencephalography (MEG), magnetic resonance spectroscopy (MRS) and transcranial magnetic stimulation (TMS) (Boly et al., 2015; Stiles et al., 2015).

The development of structural neuroimaging dates back to the early 1970s. At that time, a breakthrough technique, computed axial tomography (CAT), now better known as computed tomography (CT), was introduced that revolutionised the field of neurology as clinicians were able to view the living brain non-invasively with standard X-rays showing the bones and surrounding tissues (Boly et al., 2015). Based on this breakthrough, many engineers and scientists are looking for new ways to create images of the internal layer of the body using technologies such as PET and SPECT (Posner and Raichle, 1994; Nowosielski and Radbruch, 2015).

Although CT is widely available, magnetic resonance imaging (MRI) has become a preferred choice for cerebral imaging due to its higher sensitivity as well as its ability to perform a range of techniques without the use of ionising radiation and to provide a great depth of information (Boly et al., 2015). Magnetic resonance (MR) techniques are well established to provide high-quality structural details. They are evolving to provide various clinically valuable physiological data, such as spectroscopic studies highlighting the details of biochemical status with MR spectroscopy or MRS, blood oxygenation level enabling functional activation studies with functional MRI or fMRI, cerebral blood compartment with MR angiography or MRA, perfusion using perfusion-weighted MRI or PWI, water molecular diffusion technique with diffusion-weighted imaging or DWI, fiber tracking and cerebral microstructure using diffusion anisotropy effects by diffusion tensor imaging or DRI and magnetisation transfer imaging or MT (Boly et al., 2015; Nowosielski and Radbruch, 2015; Stiles et al., 2015). The most common way to look at the structure of the brain these days is by using MRI (Boly et al., 2015).

This review focuses on fMRI due to the limited review and empirical evidence gathered on the brain area activation in learning and memory patterns stimulated by numerals experiments. To identify neuronal activation, fMRI can provide high-resolution images by using blood-oxygenated-level-dependent (BOLD) (Pauling and Coryell, 1936). This technique is non-invasive and does not require ionising radiation to obtain rich functional data (Boly et al., 2015; Nowosielski and Radbruch, 2015; Laumann et al., 2017; Stiles et al., 2015; Pauling and Coryell, 1936). The fMRI technique can detect increased blood oxygen concentration with increased neuronal activity (Boly et al., 2015; Nowosielski and Radbruch, 2015; Laumann et al., 2017; Stiles et al., 2015; Pauling and Coryell, 1936). The typical brain responds to anaerobic metabolism when there are bursts of neuronal activity, even when plenty of oxygen is available. Increased blood flows into the brain without a corresponding rise in oxygen consumption occurs when neuronal activity rises, raising the oxygen concentration in the tiny veins that drain the active neuronal centres (Boly et al., 2015; Laumann et al., 2017; Pauling and Coryell, 1936). As neuronal activity rises, oxygen supply increases, but demand does not, and the extra oxygen delivered to the active regions of the brain returns to the general circulation via draining veins. The signal from BOLD is based on oxygenated and deoxygenated haemoglobin (Laumann et al., 2017; Pauling and Coryell, 1936). This leads to local changes that can cause magnetic resonance signals that can be used as markers of function.

7.0 BRAIN ACTIVATION REGIONS

The ten articles examined were published between 1999 and 2022, including two from the last ten years and eight from the last twenty years. The studies examined in this review were conducted in different geographical continents, including China, France, Germany, Norway, the Netherlands, and the United States of America. All studies included fMRI neurotechnology in their design (Huijbers et al., 2009; Lycke et al., 2008; Munk et al., 2002; Nie et al., 2019; Pinel et al., 1999; Schendan et al., 2003; Schmithorst and Brown, 2004; Shum et al., 2013; Walter et al., 2003; Yi et al., 2009). Most studies (70%) used memory tasks in their paradigm (Lycke et al., 2008; Munk et al., 2002; Nie et al., 2019; Pinel et al., 1999; Schendan et al., 2003; Shum et al., 2013; Walter et al., 2003), one study used a fraction problem-solving task (Schmithorst and Brown, 2004), one study used a recognition task (Yi et al., 2009), and one study used a combination of word retrieval and scene encoding task (Huijbers et al., 2009). The tasks in each article are further presented in **Table 1,** and the study characteristics are summarised in **Table 2**.

Table 2. Study characteristics of eligible articles.

Study Characteristics		**Count (n)**	**Percentage (%)**
Country	China	1	10
	France	1	10
	Germany	2	20
	Netherlands	1	10
	Norway	1	10
	United States of America	4	40
Published Year	1999-2004	5	50
	2005-2010	3	30
	2011-2016	1	10
	2017-2021	1	10
fMRI task	Memory task	7	70
	Fraction problem task	1	10
	Word retrieval task	1	10
	Scene encoding task	1	10
	Recognition task	1	10

The results show brain activation related to learning and memory for numerals in the hippocampus, inferior parietal lobe, parietal lobe, anterior cingulate, caudate nucleus, cerebellum, frontal lobe, inferior frontal gyrus, inferior temporal gyrus, medial temporal lobe, occipital lobe, prefrontal cortex, striatum, thalamus, bilateral occipital cortex, cingulate gyrus, dorsal middle frontal gyrus, dorsolateral prefrontal cortex, insula, left middle temporal gyrus, left perisylvian, left precentral gyrus, left superior frontal gyrus, left ventral prefrontal cortex, posterior parietal cortices, precuneus, putamen, right dorsal prefrontal cortex, right fusiform gyrus, temporo-occipital incisure, and ventral occipital areas (Lycke et al., 2008; Munk et al., 2002; Nie et al., 2019; Pinel et al., 1999; Schendan et al., 2003; Shum et al., 2013; Walter et al., 2003; Yi et al., 2009).

From the results collected (refer to **Table 3**), 30% of studies found activation in the hippocampus (Nie et al., 2019; Schendan et al., 2003; Shum et al., 2013), inferior parietal lobe (Munk et al., 2002; Schmithorst and Brown, 2004; Yi et al., 2009), and parietal lobe (Lycke et al., 2008; Munk et al., 2002; Nie et al., 2019). Subsequently, 20% of studies found activation in the anterior cingulate (Munk et al., 2002; Pinel et al., 1999), caudate nucleus (Nie et al., 2019; Schendan et al., 2003), cerebellum (Lycke et al., 2008; Nie et al., 2019), frontal lobe (Munk et al., 2002; Nie et al., 2019), inferior frontal gyrus (Lycke et al., 2008; Nie et al., 2019), inferior temporal gyrus (Nie et al., 2019; Shum et al., 2013), medial temporal lobe (Huijbers et al., 2009; Schendan et al., 2003), occipital lobe (Lycke et al., 2008; Nie et al., 2019), prefrontal cortex (Huijbers et al., 2009; Walter et al., 2003), striatum (Nie et al., 2019; Schendan et al., 2003), and thalamus (Nie et al., 2019; Pinel et al., 1999). Other brain regions that were activated are summarised in **Table 3**.

In summary, many brain regions are involved, each performing its function regarding learning and memory for numerals. However, the results were too different, and a region found in one study may not be discovered in another, even though the researchers were interested in the memory systems of the brain. These differences could be due to the tasks involved, the kind of stimuli used in the tasks, and the study population. The three most highlighted regions, namely the hippocampus, inferior parietal lobe, and parietal lobe, are visually presented in **Figure 3**.

From the findings of the articles reviewed, the regions that were commonly found to be active seeming share functions for memory. The hippocampus is suggested to be responsible for episodic memory and plays a huge role in spatial representation (Ferbinteanu, 2019; Lisman and Redish, 2018; Manohar et al., 2017), while the prefrontal-parietal network contributes to memory selection as well as maintaining attention on relevant information on the task and may proactively lessen the proactive interference in the working memory (Yi et al., 2009).

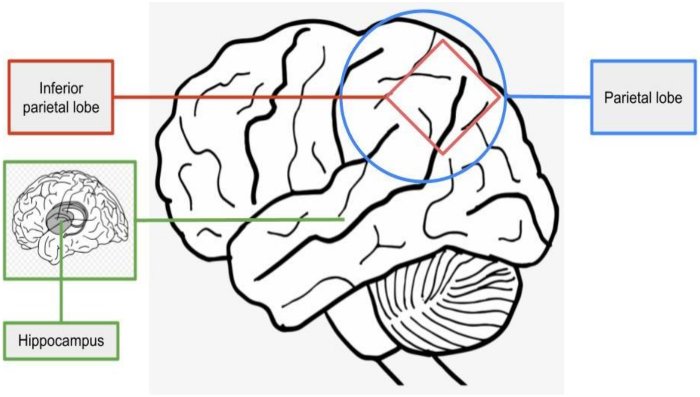

Figure 3. Three common findings from the 10 articles of brain activation regions activated during learning and memory for numerals.

8.0 CONCLUSION

The collected articles yielded various findings on the activation of the brain regions such as the hippocampus, inferior parietal lobe, parietal lobe, anterior cingulate, caudate nucleus, cerebellum, frontal lobe, inferior frontal gyrus, inferior temporal gyrus, medial temporal lobe, occipital lobe, prefrontal cortex, striatum, thalamus, bilateral occipital cortex, cingulate gyrus, dorsal middle frontal gyrus, dorsolateral prefrontal cortex, insula, left middle temporal gyrus, left perisylvian, left precentral gyrus, left superior frontal gyrus, left ventral prefrontal cortex, posterior parietal cortices, precuneus, putamen, right dorsal prefrontal cortex, right fusiform gyrus, temporo-occipital incisure, and ventral occipital areas. The three main structure involved with learning and memory is further summarised in **Figure 3**. Further studies are needed to provide more consistent results for brain activation in learning and memory patterns for numerals. Therefore, it is suggested that future studies examine the neural activation involved in learning and memory systems such as STM, which is associated with numerals. Moreover, future studies may include multimodal techniques like activation likelihood estimation (ALE) meta-analysis.

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Author Contributions: MHS plan and construct the study design and edit the manuscript, AIAH design the framework and edits the manuscript, IAIZ. interpreted the outcome and discussion.

Conflicts of Interest: The authors declare no conflict of interest.

Table 3. Findings of brain activation regions from previous studies.

Brain activation regions	Findings from previous studies	Count (n)	Percentage (%)	Brain activation regions	Findings from previous studies	Count (n)	Percentage (%)
hippocampus	• Nie et al. (2019) • Schendan et al. (2013) • Shum et al. (2013)	3	30	cingulate gyrus	• Nie et al. (2019)	1	10
inferior parietal lobe	• Munk et al. (2002) • Schmithorst et al. (2013) • Yi et al. (2009)	3	30	dorsal middle frontal gyrus	• Yi et al. (2009)	1	10
parietal lobe	• Lycke et al. (2008) • Munk et al. (2002) • Nie et al. (2019)	3	30	insula	• Munk et al. (2002)	1	10
anterior cingulate	• Munk et al. (2002) • Pinel et al. (1999)	2	20	left middle temporal gyrus	• Lycke et al. (2008)	1	10
caudate nucleus	• Nie et al. (2019) • Schendan et al. (2013)	2	20	left perisylvian	• Schimithrost et al. (2013)	1	10
cerebellum	• Lycke et al. (2008) • Nie et al. (2019)	2	20	left precentral gyrus	• Lycke et al. (2008)	1	10
frontal lobe	• Munk et al. (2002) • Nie et al. (2019)	2	20	left superior frontal gyrus	• Lycke et al. (2008)	1	10
inferior frontal gyrus	• Lycke et al. (2008) • Nie et al. (2019)	2	20	left ventral prefrontal cortex	• Walter et al. (2003)	1	10
inferior temporal gyrus	• Nie et al. (2019) • Shum et al. (2013)	2	20	posterior parietal cortices	• Pinel et al. (1999)	1	10
medial temporal lobe	• Huijbers et al. (2009) • Schendan et al. (2013)	2	20	precuneus	• Yi et al. (2009)	1	10
occipital lobe	• Lycke et al. (2008) • Nie et al. (2019)	2	20	putamen	• Nie et al. (2019)	1	10
prefrontal cortex	• Huijbers et al. (2009) • Walter et al. (2003)	2	20	right dorsal prefrontal cortex	• Walter et al. (2003)	1	10
striatum	• Nie et al. (2019) • Schendan et al. (2013)	2	20	right fusiform gyrus	• Pinel et al. (1999)	1	10
thalamus	• Nie et al. (2019) • Pinel et al. (1999)	2	20	temporo-occipital incisure	• Shum et al. (2013)	1	10
bilateral occipital cortex	• Munk et al. (2002)	1	10	ventral occipital areas	• Shum et al. (2013)	1	10

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