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RESEARCH ARTICLE

The Use of Functional Magnetic Resonance Imaging (fMRI) and Electroencephalogram (EEG) during Self-Reflection: A Scoping Review

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Abstract The integration of two fields, which are neuroscience and psychology has allowed a deeper understanding of the mental processes in the human mind, through the observation of biological and chemical processes in the brain and nervous system. Even though the gap between neuroscience and the human behavioral sciences is still large, the advancement of technology has helped narrow the gap, especially over the past two decades. This scoping review is aimed to explore the currently published research on self-reflection using the fMRI and the EEG. The present study describes the scope of existing research, and summarizes findings and recommendations for future work. The scoping review methodology guided by the standards of the PRISMA Extension for Scoping Reviews (PRISMA-ScR) was used. Comprehensive searches on the use of the fMRI and the EEG during self-reflection studies were conducted using several electronic databases including Scopus, Science Direct, Web of Science, Emerald Insights, and PubMed. The results obtained showed that all studies did not justify the sample size. The findings also revealed that various terms were used to describe the cognitive aspect of a self-reflection process. The brain functional connectivity data were taken through several experimental stages, which shows the flexibility of the experimental process. The activation of the prefrontal cortex (PFC) is one of the most commonly found regions in most studies, together with other areas associated with the self-reflection process. Based on the results obtained, this scoping review is believed to provide a comprehensive summary of the existing research on self-reflection using neuroimaging techniques.

Keywords: Neuroimaging, fMRI, EEG, self-reflection.

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Introduction

The increasing interest in brain studies is beginning to reveal the role of the human brain during the learning process. The emergence of educational neuroscience as an interdisciplinary research field has led to the development of new educational practices and policies [1-5]. Past studies have shown that the learning process involves the development and maintenance of neural pathways in the brain that facilitate the flow of information between brain cells [6]. Therefore, as human cognitive function develops over time, it is no longer sufficient to only study their behavioural change. Further investigation towards the brain development is crucial to compliment the extensive understanding of behavioural phenomena [6-7]. Neuroimaging techniques are widely used amongst neuroscientists to measure brain activity with the most commonly used techniques to record brain activity being the Functional Magnetic Resonance Imaging (fMRI) and the Electroencephalogram (EEG).

The fMRI technique has become the most common method used by scientists and researchers due to its ability to capture high-resolution images of brain regions while they are active [8-10].It can capture the changes in brain activity within brain regions to a depth of 1–10 mm, hence providing excellent spatial resolution accuracy [9]. However, the tasks that could be conducted during the experimental procedure will be limited as research participants will have to lie still in the fMRI tube. Also, the procedure is very

costly and can only take place in authorized facility centres [9,11]. On contrary, an EEG allows research participants to move more freely but lacks the spatial resolution accuracy as it can only capture the brain electrical activity on the brain surface. However, it provides high temporal resolution which allows the changes in brain activity to be captured accurately [12].

Furthermore, the EEG can compare a research participant's left and right hemispheres thereby enabling the measurement of left hemisphere dominance related to positive or negative emotional responses associated with withdrawal-related tendencies, which is crucial for self-awareness tasks such as self-reflection [13-14]. Therefore, the EEG can be considered as the most commercially popular technique due to it being much cheaper than fMRI [9]. In Malaysia, both techniques are fairly accessible in institutional facilities, though fMRI would require extensive training and funding as compared to the EEG [9,11].

Both the above neuroimaging techniques are non-invasive techniques used to capture cognitive processes that take place in human brains. The fMRI signals will not show the activity of neurons but the activation of the brain regions will be perceived through the presence of oxygenated blood [9]. The highly activated brain regions will be displayed through the multicolour image which reflects the blood flow in the brain [9-10]. The images captured would allow a further understanding of the specific localization of brain activity. On the other hand, EEG represents the electrical responses in the brain obtained by electrodes attached to the scalp. As the brain responds to certain stimulus, the signals recorded can be further analysed to identify the electrical activities that take place in the brain [9-11]. The EEG represents the electrical responses in the brain obtained by electrodes attached to the scalp. When the brain responds towards a stimulus, the signals recorded can be further analysed to identify the electrical activities that take place in the brain [9,12].

The electrical impulses produced in various brain areas are signs that the brain is engaged in cognitive processes. Cognitive neuroscience studies focus on how brain neurons' chemical and physical activity reflects cognitive function [13–14]. Active representations in the brain are patterns of neuronal activity, which propagate activity during cognitive processes, with learning and memory are fundamentally the consequences of changing connections [15–16]. While some scientists argue that individual brain areas perform unique, contained processing functions, others argue that each region contributes uniquely to a distributed interaction process, the representation of which may be obtained through neuroimages [9,11–12].

The relationship between cognitive neuroscience and human behavioural change is inevitable. As individuals automatically or deliberately engage themselves in an effortful conscious control of various types of cognitive processing, this would either directly or indirectly influence their behavioural decisions [15]. Within the field of cognitive neuroscience, many researchers seek to use observations from brain studies to help unravel the mechanisms of the mind. Reflection is one of the cognitive processes that is regarded as a high cognitive function, which enable individuals to witness and evaluate their own cognitive, emotional, and behavioural processes. Self-reflection requires high cognitive functions as its process is highly effortful and voluntary [16-17]. The ability to evaluate, organize, achieve goals and be flexible when challenged with sudden changes or difficult situations are classified as high cognitive functions [18-19]. Much previous research has depended on the traditional self-report questionnaires to study participants' reflective practice whilst there has been little scientific evidence captured during the cognitive process itself [20-27].

Recent research findings on brain activities during cognitive tasks have managed to represent the scientific data obtained using either; fMRI or the EEG, or both simultaneously. However, much of the research focused on human executive functions including complex problem solving, decision-making and critical thinking [18-19, 28-31]. As a result, especially in Malaysia, there has been little research using neuroimaging techniques focusing on self-reflection activities. Therefore, it is uncertain what kind of information is available in the literature about the experimental procedures, including the task structures, the common terms used to describe the cognitive state during reflection, the techniques used for the experiments and the neural activities that occur during the process of self-reflection.

For these reasons, a scoping review was conducted in order to map systematically the research done in this area, as well as to identify any existing gaps in the knowledge. Following the primary research question – What research has been conducted using fMRI and EEG to study reflective thinking? – the following sub-questions were formulated:

1) What populations have been studied?
2) What are the terms used to describe the cognitive state during reflective thinking?
3) What are the experimental structures used in the studies?

4) What are the current findings on neural activities that occur during reflective thinking?

Methodology

A thorough literature review on the use of fMRI and EEG neuroimaging methods during reflection was conducted. The reviewers adopted a scoping study to enable a more comprehensive search that considers the reproducibility, transparency, and trustworthiness of the existing literature, which focuses on using specific tools to analyze brain processes during the reflective process [32].

The reviewers believe that a scoping review is more appropriate in the present study as it provides a preliminary assessment of the currently available research on the topic compared to the more specified focus of a systematic review [32-34]. It aims to identify the nature and extent of the research evidence [34-35], which is more suitable for a more comprehensive understanding of the current types of evidence available, the key concepts and the standard research methodologies utilized in this area [35-36]. The results of this scoping review will serve as a precursor for a future systematic review aimed at addressing specific research questions. The reporting of this scoping review was guided by the PRISMA Extension for Scoping Reviews (PRISMA-ScR) standards, which follow the five steps described by Arksey and O'Malley [33]:

1. Identification of the research questions
2. Identification of relevant studies
3. Selection of relevant and reliable studies
4. Data extraction from the included studies
5. Collating, summarizing and reporting the findings

Database Search Strategy

This scoping review paper used the search strategies and review process that has been published in the previous works. Briefly, the search strategy included a set of keywords on the use of the fMRI and EEG, and the neural correlates during self-reflection activities through electronic databases such as Scopus, Science Direct, Web of Science, Emerald Insights, PubMed and bibliographic search. An example of a search strategy for one of the databases can be seen below :

Scopus Search Strategy Performed: 22nd November 2022

reflect* AND think* OR reflect* OR self- AND reflect* OR reflect* OR self-referenc* AND neural AND network AND brain AND functional AND connectivity OR us* AND neuroimagin* AND techniqu* AND fmri OR eeg AND PUBYEAR > 1999 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SUBJAREA , "NEUR") OR LIMIT-TO (SUBJAREA , "MEDI") OR LIMIT-TO (SUBJAREA , "PSYC") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (EXACTSRCTITLE , "Brain Research") OR LIMIT-TO (EXACTSRCTITLE , "Neuroimage") OR LIMIT-TO (EXACTSRCTITLE , "Neuroscience And Biobehavioral Reviews") OR LIMIT-TO (EXACTSRCTITLE , "Human Brain Mapping"))

Identification of Relevant Studies

An electronic search was conducted in November 2022 using several electronic databases including Scopus, Science Direct, Web of Science, Emerald Insights and PubMed. These databases were used to obtain further information on neural activities using fMRI or EEG that take place in the human brain during self-reflection. Based on the search limited to full-text English language published journal articles, a series of published articles related to the keywords from the years 1977 to 2022 was found.

The articles in this study are selected from the search results based on criteria set for detailed consideration. This review only includes the peer-reviewed and original papers published in international and national journals from the years 1981 to 2022. All selected articles are the reports on studies regarding self-reflection with data was gathered through non-invasive neuroimaging techniques, specifically fMRI and EEG. All articles from the searches were transferred to an online reference manager software; scribbr.com and Microsoft references manager. All duplicates and titles in language other than English were removed. The PCC (Participants, Concept and Context) framework was used to establish eligibility criteria [38].

In order to be included, original peer-reviewed articles had to meet three criteria. First, the study considered fMRI and the EEG as the main data collection tools that involve participants. Any studies that used other neuroimaging techniques were excluded. Second, the studies should be focusing on the

thinking process, specifically reflection-related tasks. Observational and interventional studies or both were included. Third, the outcome of the study should clearly state the neural correlates with self-reflection in cognitive perspectives. Any studies that used terms synonymous with self-reflection were also included, which inclusion would be based on the task(s) conducted during the experiment. The results representation could be in any two or all three of neuroimaging data, statistical data and behavioural data. However, the neuroimaging outcomes measured in the study are reported from a brain anatomical perspective, as listed in Table 1.

Selection of Relevant and Reliable Studies

Reviewers with educational psychology and electrical engineering backgrounds have screened the articles for selection using the eligibility criteria. The first selection was from title and abstract screening and the second one was from a full-text screening. Once the articles were selected, the following data were recorded in a spreadsheet: author(s), year, characteristics of participants, participants' inclusion and exclusion criteria, study objective(s), type of research design, the experimental task design, the task's stimulus, the participants' responses, the post-experimental task(s) (if applicable), measurement methods, outcomes measured and the key findings. The focus of this review will solely be on the findings of currently published research, not the quality of that research. However, the researchers developed a list of quality appraisal criteria to facilitate the data extraction process for study reporting.

The reviewers combined several established quality appraisal tools to suit the nature of the research in the included articles (see Appendix 1). As the data acquisition tools are categorized as clinical tools (fMRI and EEG), this scoping review only focuses on the clinical studies which focused only on experimental studies. The authors have instead opted to develop a 13-item checklist based on criteria and questions sourced from the following quality assessment tools; assessment tool for observational cohort and cross-sectional studies, and assessment tool for before-after studies with no control groups to facilitate the theme identification process [40-42].

Table 1. Regions of Interest (ROI) in Comparison to Study Findings

Author/Year	Neuroimaging method	ROI	Neural Activity found in the studies that majorly associated with self-reflection			
			Prefrontal Cortex (PFC)	Cingulate Cortex (CC)	Anterior Insula (AI)	Other
Packer and Cunningham (2000) [43]	fMRI	PFC	dlPFC, vlPFC	aCC		
Gusnard *et al*. (2001) [44]	fMRI	mPFC	dmPFC			
Johnson *et al*. (2002) [45]	fMRI	mPFC	mPFC	pCC		
Johnson *et al*. (2006) [46]	fMRI	Anterior and Posterior Medial Region	dmPFC	pCC		
Esslen *et al*. (2008) [47]	EEG and fMRI	mPFC	dmPFC			
Johnson *et al*. (2009) [48]	fMRI	aMC, mPFC				
Modinos *et al*. (2009) [49]	fMRI	Insula and Brain Midline Structure	mPFC	aCC		
Whitfield-Gabreli *et al*. (2011) [50]	fMRI	*Not Reported*	mPFC	pCC		
Herwig *et al*. (2012) [51]	fMRI	mPFC, CC, vLPFC, dLPFC	dlPFC and mPFC		•	
Fingelkurts *et al*. (2013) [52]	EEG	*Not Reported*	Operation Module (Frontal, Posterior and Left Posterior)			
Ma *et al*. (2013) [53]	fMRI	dmPFC, dACC, Insula	dmPFC	dACC	•	
Zhu *et al*. (2013) [54]	fMRI	mPFC	dmPFC		•	
Baek *et al*. (2017) [55]	fMRI	mPFC, PCC	mPFC, vmPFC and dmPFC			TPJ - Left
Cooper et al. (2017) [56]	fMRI	mPFC, pCC	mPFC	pCC		
Scherpiet *et al*. (2018) [57]	fMRI	*Not Reported*				
Vartanian *et al*. (2018) [58]	fMRI	PFC and aCC		aCC, pCC		
Ciorciari *et al*.	fMRI	vmPFC, CC, oFC	mPFC, vmPFC			

Author/Year	Neuroimaging method	ROI	Neural Activity found in the studies that majorly associated with self-reflection			
			Prefrontal Cortex (PFC)	Cingulate Cortex (CC)	Anterior Insula (AI)	Other
(2019) [59]			and dLPFC, oFC			
Kedia (2019) [60]	fMRI	mPFC, AI, PCC	mPFC	aCC	•	
Rominger *et al.* (2020) [61]	EEG	Frontal and Parietal side				Occipital site
Zhen and Yu (2021) [62]	fMRI	mPFC	dmPFC			

dlPFC= Dorsolateral PFC, vlPFC = Ventrolateral PFC, dmPFC = Dorsomedial PFC, mPFC = Medial PFC, aMC = Anterior Medial Cortex, vmPFC = Ventromedial PFC, oFC = Orbitofrontal Cortex, aCC = Anterior CC, pCC = Parietal CC, daCC = dorso anterior CC, and TPJ = Temperoparietal junction.

Reporting the Findings

A chronological representation of included studies was prepared to present the patterns in neuroimages and statistical analysis used to present the data in the study. A numerical analysis presented the number of studies that use fMRI and EEG or both the as data acquisition tool, stimulus task research years on a decade-basis and the type of analysis used in the studies. The reported outcomes and findings were synthetized and grouped into specific themes defined by the authors based on the sequence of the research questions to illustrate the narrative account as seen in Table 2.

Results and Discussion

Identification of Relevant Studies

A detailed summary on the strategies and processes involved in the literature search is shown in Figure 1. The four common steps of a literature search were used before finalizing the relevant articles to be used in the study: (1) Identification, (2) Screening, (3) Eligibility and (4) Final Inclusion. During the identification process, a series of published articles was found through the database search specifically on the use of fMRI and EEG during self-reflection. During this stage, the inclusion criteria are any original peer-reviewed articles that were published in national and international journals from the year 1977 to 2022. A total of 728 articles were identified from databases and other sources. After removing 12 of duplicate records, automation tools were used to exclude non-related articles (n=428) during the screening process. A total of 240 additional articles were then screened by viewing titles and abstracts viewing. The articles included in the screening stage are non-clinical studies concerning the self-reflection. After the screening process was completed, 47 full-text articles were retrieved for assessment. To find out the eligibility of the remaining articles, a thorough full-text review was conducted and articles with irrelevant scope, insufficient details and limited rigor were excluded. After this viewing process, only 20 articles were found to be eligible by meeting the criteria of the study. Figure 1 shows the study identification and selection process.

Table 2. The number of studies based on the Neuroimaging techniques

Neuroimaging Technique as Data Acquisition Tool	Number of Studies
EEG	2
fMRI	17
Both	1
Total	**20**

Type of Research Method and Design

All of the studies reviewed were categorized as clinical observational studies. Two (10%) of the studies, used an experimental task and a control task in their research though no participant was put in a treatment group. The experiments were conducted between two different groups in order to observe the difference in any behavioural or neural results. For example, one of the studies was conducted amongst participants with Major Depressive Episode (MDE) as their experimental group to examine the differences in the neural activities involving the engagement of the anterior medial cortex between the depressed participants and the controls [48]. Another 10% (n=2) of the studies adopted interventional measures during their clinical experiments. However, the aim was only to see whether the intervention used could improve the behavioural outcome amongst the same group of participants. For instance, a study was conducted to investigate the difference in electroencephalogram activity in the alpha band

during a reflection task before and after training [61]. Therefore, the nature of all the research reviewed in this paper was observational research providing data acquired through experimental tasks using clinical tools: fMRI and EEG.

This study reviewed 20 journal articles, ranging from the year 2000-2021. Figure 2 shows the number of studies by decade and there were no studies related to neural activities during self-reflection was found prior to the year 2000. The bar chart shows that the number of studies significantly increased over the past couple decades. Similar to human brain, the technologies used to study brain functional connectivity is also improving over time. The increasing attention to neuroscience is not surprising despite its costly approach. However, neuroimaging studies are beginning to demonstrate an ability to correlate mental states and traits to detectable brain patterns or structures [63].

In the past, to ascertain the function of a particular brain region, neuroscientists depended on injuries or pharmacological interventions in animals. Nonetheless, within the last 20 years, researchers have become more adept at accurately manipulating circuits in animal models because of the development of novel genetic methods [64–66]. The knowledge of the circuits governing memory, motor control, and sensory processing has increased due to these investigations. Consequently, it will be critical to understand what all neurons are encoding, not just the neurons that are task-responsive or that support the particular hypotheses in the study when neuroscientists sample more neurons with high-density electrodes or imaging techniques [65].

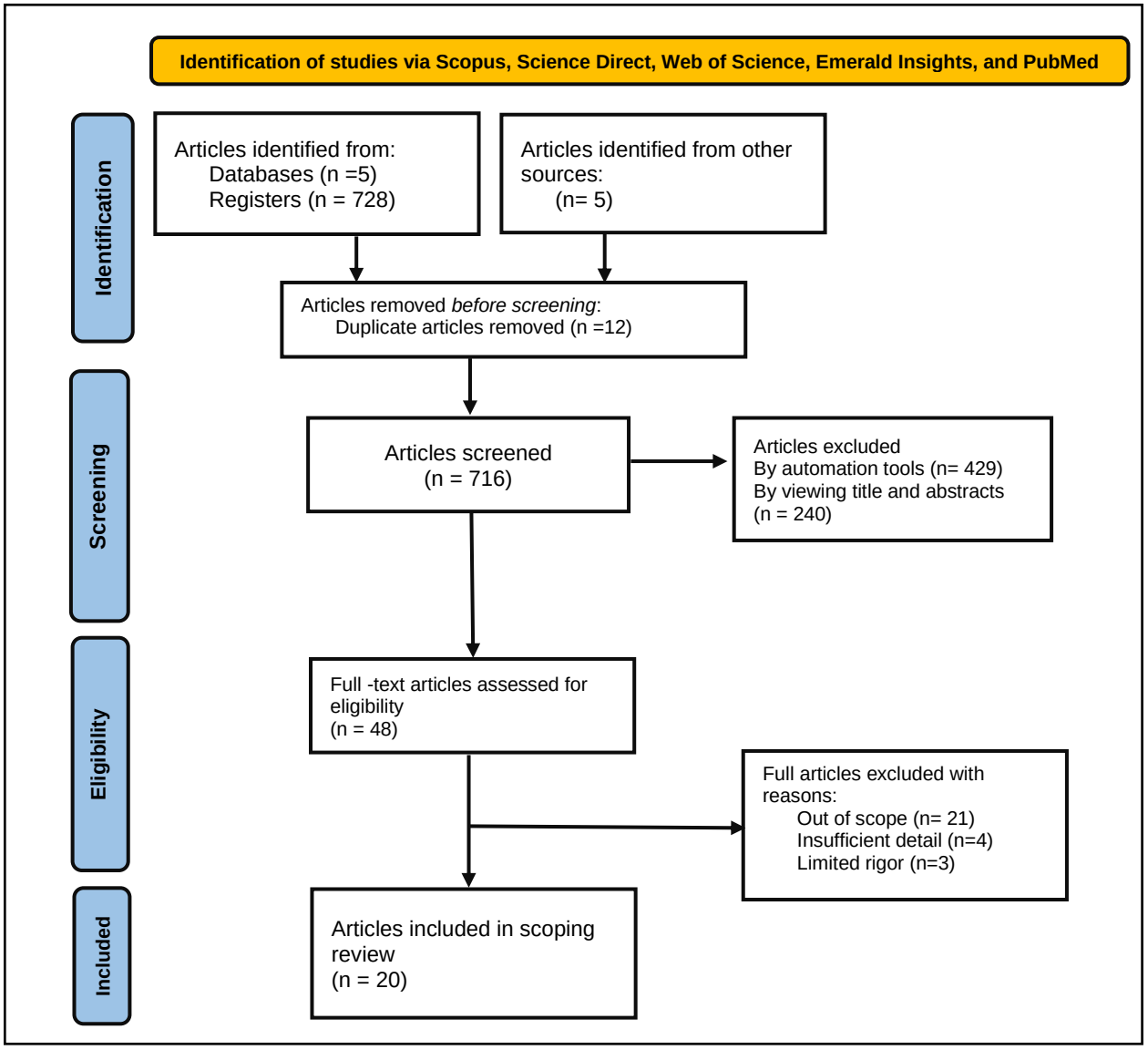

Figure 1. Flow Chart of the Studies Identification and Selection Process

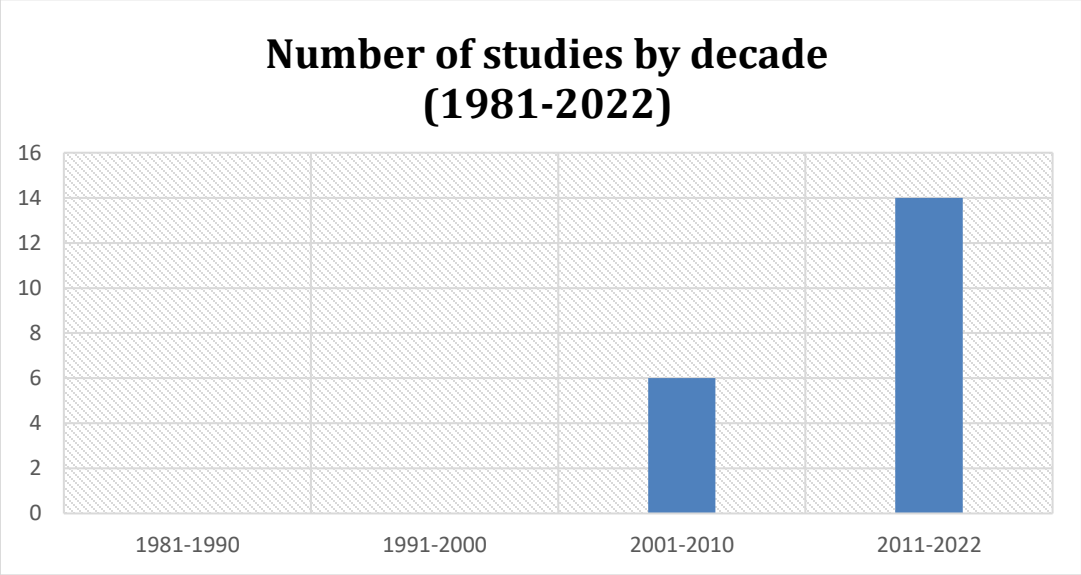

Figure 2. Number of Studies by Decade

Study Population

In clinical-based research, the population refers to a group of people who share a common characteristic or a condition which is unique and specific. Most of the studies reviewed in this paper justified the characteristics of the subjects eligible for their research. The researchers defined the specific and unique characteristics required to participate in their research through the listing of inclusion and exclusion criteria. Of the studies reviewed, very few mentioned the exclusion criteria which specify the unique characteristics of the participants required for the study. However, most studies mentioned that the research participants had to meet standard fMRI eligibility criteria, which include having no metal implants in their body, being right-handed, and not being pregnant or claustrophobic. Participants with a history of major health problems or mental illness were excluded. Amongst all of the studies reviewed, only two studies used different groups of participants in their studies, which inclusion criteria included vulnerable participants.

Based on the review, none of the studies justifed their sample size. The use of sample size calculation directly influences research findings. Very small samples would undermine the internal and external validity of a study. On the other hand, too large samples tend to transform small differences into statistically significant differences even when they are clinically insignificant. However, in experimental studies, a larger sample size does not guarantee the data's validity. Most studies reviewed are conducted to study a certain behavioural phenomenon, which classifies them as observational.

Characteristics of Participants

All of the studies described the participants involved in their research but only one (5%) study justified the sample size chosen. Even though the studies reviewed were classified as clinical research, there was no clinical trial involved in any of the studies. However, it is very important for every clinical research to clearly state the inclusion and exclusion criteria in choosing their participants. This is to ensure the identification of the study population is reliable and consistent. The review showed that two (10%) of the studies recruited different categories of participants, which were divided into a task group and a control group. The control groups in these studies were recruited from among the vulnerable sample. The vulnerable participants that were recruited as the experimental group were screened uniformly before they were categorized eligible for the group. 12 (85%) of the studies recruited low-risk participants and the same participants were used throughout the experimental procedures. Meanwhile, only 1 (5%) of the studies recruited two groups of participants, as the study conducted two different experiments and each group was assigned to only one experiment.

Inclusion and Exclusion Criteria

Based on the review, five (25%) of the studies did not report any participant inclusion criteria and 4 (20%) of the studies did not include any exclusion criteria. Amongst these figures, a total of three (15%) of the

studies failed to mention both inclusion and exclusion criteria. Amongst the studies with inclusion criteria mentioned 15 (75%), 10 (66.6%) of them required all of their participants to be right-handed. Another common inclusion criteria required the participants with normal or corrected-to-normal visual acuity six (40%). Three (50%) of the studies include both characteristics as inclusion criteria. A total of 13 (87.67%) studies mentioned more than one inclusion criteria. Other inclusion criteria included the participants' unique characteristics, such as long-term meditators and Swiss-German native speakers. For the two (13.33%) studies with vulnerable subjects mentioned earlier, subjects with borderline personality disorder and major depressive episode inclusion were screened using psychometric tests and by medical personnel before they were declared eligible for the study.

Exclusion criteria are also important in clinical research especially as the data acquisition tools are highly technology-dependent. 16 (80%) of the studies reported the exclusion criteria of their studies. Apart from the studies with vulnerable patients used as the experimental group 2 (12.5%) other studies used the standard fMRI eligibility criteria, which include participants with no history of head trauma, or any psychiatric disorders, or substance abuse, and appropriate current medication status (n=14, 87.5%).

The nature of these studies reviewed are clinical-based research whereby one or two specific clinical tools were used. Hence, it is important for all research to be pre-approved by the local ethics committee before. Based on the review, 17 studies have reported that they had obtained informed consent from the participants, which had been approved by their local ethics committee. As all of the research used humans as their subjects, it is crucial to have their study protocol approved to ensure the validity of data obtained during experiments.

Terms Used to Describe the Cognitive Process Studied

The included articles used a variety of terminologies to study cognitive processes that involved the activity of self-reflection. Of these terminologies 10 studies used the term 'reflection' or 'self-reflection' to describe the self-thought process, four studied 'participants' self-referential'. Meanwhile, the remaining studies each used different terms: 'Self-relevance', 'self-affirmation', 'self-regulation', 'self-processing', 'reflective thinking' and 'interpersonal thinking'. Even though the terms used to represent the cognitive processes in the studies differ, task(s) conducted in each studies' experiment included at least one reflective task. Therefore, all of the terms used in the reviewed studies indicate the reflective thinking activity.

Screening Test

In general, the use of screening tests is to assess whether prospective subjects are appropriate candidates for inclusion criteria in studies is an appropriate pre-entry activity, though it's necessity would depend on the criteria set for subjects' recruitment. The experimental formats differ according to the research questions and objectives. However, as explained in the earlier results section, very few studies used vulnerable participants as subjects in their studies. Therefore, those studies conducted screening tests prior to the actual experiment to ensure the subjects involved in their studies were truly eligible and met the inclusion and exclusion criteria. Screening tests are usually conducted before the subjects are finalized. Besides identifying vulnerable participants, screening is also crucial when the researchers would like to study a specific group of people and to make sure that the uniquely required criteria are met.

For example, based on one of the studies reviewed, which was conducted by Corciari *et al*., (2019) [59], the researchers wished to recruit 40 participants with an equal chance of representing their personality orientation based on the Gountas Personality Orientation (GPO) Test. The researchers decided to run a screening test with 48 participants before eliminating eight of them in order to ensure each personality orientation was being represented by 10 participants, regardless of gender. Another study that used a screening test prior to the actual data collection procedure is a study conducted by Scherpiet *et al*. (2014) [57]. The study aimed to recruit participants with borderline personality disorder (BPD) and control group. Therefore, the healthy control (HC) participants were screened for Axis-I psychiatric diagnoses, which is recognized as the exclusion criterion using the Mini-International Neuropsychiatric Interview. Meanwhile, the participants with a BPD diagnosis had it confirmed through physician referral using an extensive assessment which included structured interviews, background and previous psychiatric records. This process was vital to ensure the study's objective was achieved.

The Experimental Structure

The studies conducted used either the fMRI or EEG tests or both as data acquisition tools to capture brain activities and function during a certain thinking process which was stimulated in order to achieve the study objectives. All of the studies used different experimental procedures, which were developed

through study protocols. In general, study protocols in any clinical-based research should comply with any local ethics committee requirements before starting their study. The experimental structures and tasks are designed according to the researchers' interests. Therefore, the approval from a research ethics committee would validate the competency of a particular protocol. Some studies conducted pre-experimental tasks before the scanning (using fMRI and EEG) and this might require the participants to complete the main task while doing so. After the brain activity is recorded, some studies required their subjects to participate in post-experimental tasks.

There were three experimental structure patterns found from the studies reviewed: the 1-stage experiment, 2-stage experiment and 3-stage experiment. The stages are known as the pre-experiment, during experiment (main task) or post-experiment. The 1-stage experiment refers to the studies that did not conduct any pre- or post-experimental task and only used the main task (while being recorded by the fMRI and EEG) to achieve the study aim. There are two types of 2-stage experiment. The first type is when the study conducted only the pre-experimental task and the main experimental task. The second type refers to the studies that conduct only the main experimental task and the post-experimental task. Six studies reported that they have conducted a 3-stage experiment that begins with the pre-experimental task followed by the main task and post-experimental tasks.

Reflective thinking is often described as a mental state, which process takes place in the brain. However, there should be triggering factors or stimuli to elicit the process. Most studies reviewed used visual, audio or both stimuli when conducting the experimental task. Some researchers argued that reflective thinking is a self-driven action, the depth of which could differ based on the meaning behind the event that is being reflected on. Therefore, in order to study reflective thinking in a scientific manner, a standardized stimulus needs to be introduced to ensure that each participant will be exposed to the same factor, be it internal or external. The summary the experimental structures can be seen in Table 3.

Table 3. The Experimental Stages Involved in the Studies

	Screening Test	Pre-Experiment Task	Experiment Task (Type of Stimuli)	Participants' Response	Post-Experiment Task	Total Stages
Packer and Cunningham (2000) [43]	None	None	Visual	Mental State	Yes	2
Gusnard *et al*. (2001) [44]	None	None	Visual	Yes/ No Decisions (Button Pressing)	None	1
Johnson *et al*. (2002) [45]	None	None	Audio	Yes/No Decisions (Button Pressing)	None	1
Johnson *et al*. (2006) [46]	None	None	Non-Stimulus Based	Mental State	None	1
Esslen *et al*. (2008) [47]	None	None	Visual	Yes/No Decisions (Keyboard Button)	None	1
Johnson *et al*. (2009) [48]	None	Yes	Visual	Yes/No Decisions (Button Pressing)	Yes	3
Modinos *et al*. (2009) [49]	None	None	Visual	Yes/No Decisions (Button Pressing)	No	1
Whitfield-Gabreli *et al*. (2011) [50]	None	None	Visual	Yes/No Decisions (Button Pressing)	None	1
Herwig *et al*. (2012) [51]	None	Yes	Non-Stimulus Based	Mental State	Yes	3
Fingelkurts *et al*. (2013) [52]	None	Yes	Audio	Mental State	Yes	3
Ma *et al*. (2013) [53]	None	Yes	Visual	Likert Scale (Button Pressing)	Yes	3
Zhu *et al*. (2013) [54]	None	Yes	Visual	Yes/No Decisions (Button Pressing)	Yes	3
Baek *et al*. (2017) [55]	Yes	Yes	Visual and Audio	Verbal, Mental State and Likert-Scale rating (Button Pressing)	Yes	3
Cooper *et al*. (2017) [56]	Yes	Yes	Visual and Audio	Multiple Options (Button Pressing)	Yes	3
Scherpiet *et al*. (2018) [57]	Yes	Yes	Non- Stimulus Based	Mental State	None	2

	Screening Test	Pre-Experiment Task	Experiment Task (Type of Stimuli)	Participants' Response	Post-Experiment Task	Total Stages
Vartanian *et al*. (2018) [58]	None	None	Visual	Not Reported	None	1
Ciorciari *et al*. (2019) [59]	Yes	None	Visual	Multiple Options (Button Pressing)	None	1
Kedia (2019) [60]	None	Yes	Visual	Yes/No Decisions (Button Pressing)	None	2
Rominger *et al.* (2020) [61]	None	None	Visual	Mental and Verbal	Yes	2
Zhen and Yu (2021) [62]	None	None	Visual	Multiple Options (Button Pressing)	No	1

Region of Interests (ROI)

All of the studies included in this review used fMRI and EEG as their main data acquisition tools. The main function of each tool is to produce neuroimages which represent the neural activities and the functional connectivity that occur in the brain during the cognitive process studied. The ROI is commonly identified in image processing to ensure the parts on which the researchers would like to focus on will be the minimal portion studied. Brain studies are often complex as they involve many areas and the activation of any regions could be incidental or coincidental. It could be the reference as it is usually identified through past literature and results from previous studies. Based on the articles reviewed, more than half (n=16, 80%) of the studies identified the region(s) of interests within their studies prior to data collection. The illustration of brain structure can be seen in Figure 3. Based on the review, all 16 studies managed to provide evidence of the ROI identified before the results were obtained. The summary of the ROI recognized by the researchers prior to data collection and the results comparison can be found in Table 1 and Figure 3. 11 (73.3%) of the studies developed a minimum of one hypothesis based on their research ROI.

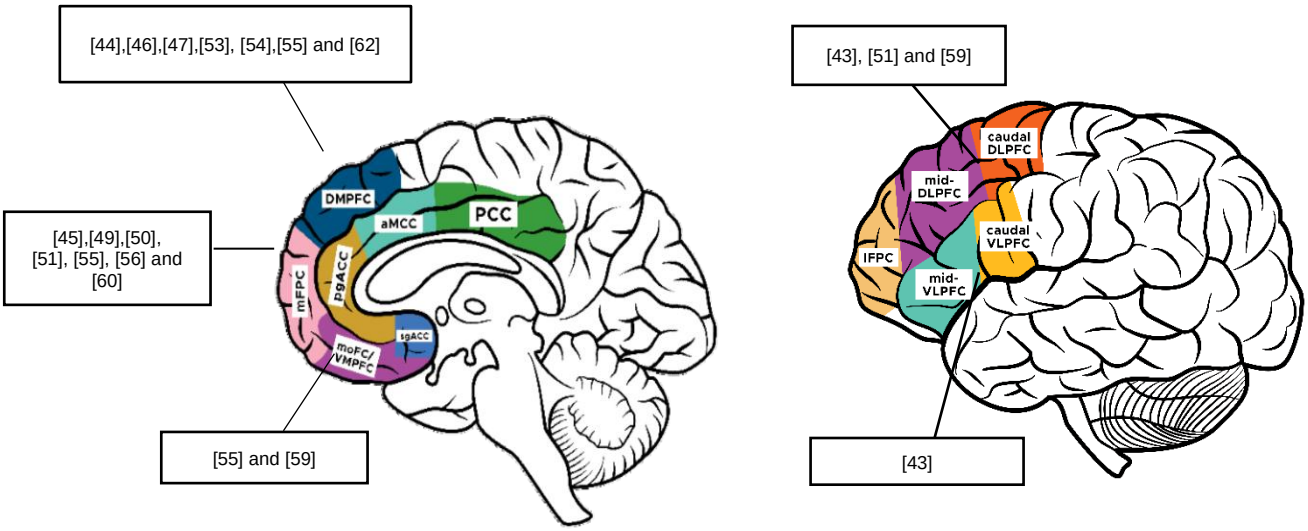

Figure 3. The brain regions in prefrontal cortex area that were found activated during the experiments

The Neural Activities Key Findings

All of the studies reviewed in this paper acquired their data using neuroimaging techniques. However, some research collected additional data supplementary to the main data set (neuroimages). Therefore, various techniques were used to analyse the different sets of data. In addition, this study only focuses on the type of neuroimaging data obtained. 10 studies mentioned the removal of artifacts and noise from the fMRI and EEG reading using various methods and nine studies did not report this. All of the studies reviewed focused on the neural findings in their research, which emphasized the brain regions associated with self-reflection. Moreover, 16 studies reported mentioning their ROI prior to their studies. Therefore, apart from discussing the outcome obtained based on the ROI, there were also additional

brain regions found associated with self-reflection discussed in the studies. The outcomes assessed were projected and explained based on the brain's anatomical perspectives using a literature review.

The results obtained include all studies using the fMRI and the EEG as the data acquisition tool to study the neural activities that occur during self-reflection. The results obtained revealed substantial evidence that the prefrontal cortex appears to be the most activated during self-processing activities. The prefrontal cortex refers to the portion of the brain located on the anterior most front area of the frontal lobe. It occupies portions of all three surfaces of the frontal lobe: the orbital, medial and lateral surfaces (refer to Figure 3). The outcome reported in most studies covered the findings in ROI determined by the researchers prior to conducting their research. On the subject of brain study, the emphasis on ROI is especially important as it provides the structural substrates to measure the connectivity within individual brains and to pool data across populations. Many connectivity alterations have been reported in various brain diseases. Thus, assessment of structural and functional connectivity has emerged as fundamental research area.

Therefore, the localization of ROI is important for brain connectivity mapping though this localization is often conflicting as some research might offer different interpretations of the results obtained in previous studies. Hence, the ROI set by researchers should be reliable and accurate. This process is vital to ensure the success of brain connectivity mapping. Many of the studies used past literature to determine the ROI in their studies. Therefore, a rigorous and thorough literature review will have to be conducted to ensure that the possible brain regions involved in a particular cognitive process were investigated at that time

Conclusion and Recommendation for Future Work

Traditionally, neuroscience is classified as a subdivision of biology that studies human nervous system, which include the brain, spinal cord and peripheral nervous system. Nevertheless, it has become an interdisciplinary science which connect closely with other fields such as engineering, medicine and psychology. The integration of several disciplines has allowed researchers to study the learn about the brain structures from different academic perspectives. This scoping review uses standard systematic review methods to identify, select, and synthesize findings from 20 studies that reported neural activities associated with self-reflection. The reviewers documented the eligible peer-reviewed literature by analysing the scope, the type of cognitive process that aligned with self-reflection mechanisms, regions of interests, the pattern of experimental structures and the type of outcome assessed. Hence, the reviewers provide important information on the implications of the findings and the gaps that emerged from the results of this review that can be relevant for researchers with similar background interests.

None of the studies reviewed was conducted in Malaysia. In addition to that, within Malaysia's educational context, most of the past studies regarding reflective thinking adopted the conventional methods of self-reports using questionnaires and open-ended questions as the main research instruments. The use of neuroimaging technique in capturing neural activities during a specific cognitive process could contribute to the scientific data that is lacking especially when cognitive processes are known as internal mental processes. The present scoping review identified a non-traditional method of assessing one's reflective thinking ability. Therefore, it is believed that through the adoption of neuroimaging technology to collect scientific data will be able to help draw the initial findings of functional connectivity during the process of reflection.

The studies reviewed in this paper revealed different tasks and activities used during the experimental procedure. The tasks functioned as the variable in order to elicit reflective thinking during the experiment. 18 out of 20 studies reviewed in this paper, used fMRI as the neuroimaging technique to capture the brain activities during self-reflection. Therefore, the tasks introduced in most studies used similar technique as the subjects' movements would be very limited and controlled. This results in limited responses that can be provided by the subjects during the task. The reflective thinking process experienced by the subjects are based on the stimulus given to them during the task, which is necessary to get their minds to reflect. In general, reflective thinking is a form of critical thinking that require an intense self-introspection which involves decision-making and problem- solving processes. Therefore, a well-structured task to stimulate critical reflective thinking could be designed to synchronize the process.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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