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Meditation Interventions improve Visuospatial Working Memory: A Systematic Review

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Abstract

In recent decades, there has been a notable increase in studies focusing on meditation-based interventions, with a primary aim of exploring their impact on both physical and mental health. The objective of this systematic review was to investigate the effect of meditation-based interventions on Visuo-Spatial Working Memory (VSWM). A search for the review was conducted through 2393 studies published between 2009 to 2023, across 10 electronics databases using consistent keywords. The review included 30 randomized controlled trials, which included both active control group and no active control group designs with a total of 1854 individuals. The studies underwent a screening process based on their titles and abstracts, and they were assessed in accordance with pre-defined eligibility criteria. These were examined with respect to participant demographics, and the outcomes. Most studies showed that meditation interventions enhance VSWM. Fewer studies targeted Focused Attention Meditation practices as compared to mindfulness meditation. The present review has also integrated EEG studies, showing the significant effect of meditation practices on brain activities in fronto-parietal regions associated with working memory and VSWM. Across all intervention types and durations, positive effects of meditation on VSWM were consistently observed. Short-term interventions (e.g., 3-8 weeks) demonstrated immediate benefits, while long-term practices (e.g., 2-10 years) showed sustained improvements in VSWM. Most studies (*n*= 24) focused on student populations, while others examined diverse age groups, including children and older adults. These findings highlight the potential for incorporating meditation practices into programs that focus on the enhancement of executive functions of individuals.

Key words: meditation intervention, visuospatial working memory, working memory, focused attention meditation, open monitoring meditation.

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Novelty and Significance

What is already known about the topic?

- Meditation interventions have been shown to improve cognitive functions, including working memory.
- Previous studies have associated specific meditation practices with increased activity in brain regions that support working memory.
- The effects of meditation on Visuo-Spatial Working Memory remain to be reviewed.

What this paper adds?

- This review provides insights into how meditation practices affect Visuo-Spatial Working Memory.
- The inclusion of EEG studies reveals insights into brain activity changes in the regions closely linked to Visuo-Spatial Working Memory.
- This review identifies gaps in the literature regarding focused attention meditation suggesting directions for future research in meditation and cognitive enhancement.

Cognitive tasks and functions play a crucial role in the processes of adaptation and learning. (Bock & Girgenrath, 2006; Shoghi Javan & Ghonsooly, 2018). Cognitive skills such as working memory, attention control, and critical thinking etc. are crucial for effectively accomplishing cognitive tasks. Working memory has been extensively studied as an essential component of executive functioning in relation to a variety of cognitive domains, including reading, writing, language, mathematical ability, information

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processing speed, and learning (Gathercol, Alloways, Willis, & Adams, 2006; Swanson & O'Connor, 2009; Pham & Hasson, 2014). Baddeley and Hitch's multi-component model of working memory (Baddeley & Hitch, 1974; Baddeley, 2000) describe working memory and its various components in detail. Working memory (WM) is temporary or short-term memory storage with central executive and two subsidiary systems: the visuospatial working memory (VSWM) and verbal working memory (VWM) (Baddeley, 2000). The phonological loop is linked to verbal working memory, which stores phonological entries. VWM maintains spoken and aural data in a temporary repository and rehearsal system (Baddeley, 2000).

VSWM is a subset of working memory concerned with the handling of stored visual information. VSWM is mainly engaged in the recollection of perceptual visual and spatial stimulus connections (Baddeley, 2000; Pham & Hasson, 2014). VSWM is primarily concerned with the production, processing, maintenance, and manipulation of visual data saved in a visuospatial sketchpad (Baddeley & Hitch, 1974; Baddeley, 2000; Pham & Hasson, 2014). Studies on VSWM have found that it is also concerned with higher level reading ability and comprehension, task performance, mathematical ability, academic achievement etc. (Gathercole, Brown, & Pickering, 2003; Pham & Hasson, 2014; Mammarella, Caviola, Giofre, & Szucs, 2017; Allen, Higgins, & Adams, 2019). VSWM is important for learning and performance of any task. And improvement in it may also improve task performance and academic attainment (Mammarella, Cornoldi, Pazzaglia, Toso, Grimoldi, & Vio, 2006). Improvement in VSWM and other components of working memory might help to improve other associated mental and cognitive abilities.

Yoga and meditation have various health benefits for the mind and body, hence these practises can be employed for an individual's necessary development both mentally and physically (Goldschmidt, 2019; Daya & Hearn, 2018; Waters, Barsky, Ridd, & Allen, 2014; Franco, Mañas, Cangas, & Gallego, 2010). Numerous studies have evinced the positive effects of yoga and meditation on reducing academic stress (Moreno, Becerra, Ortega, Suarez Ortegón, & Moreno, 2023), improving numerous mental abilities, including executive control (Lippelt, Hommel, & Colzato 2014; Moye & Van Vugt, 2019; Das, Pandey, & Krishna, 2020), improving cognitive functions and abilities (Ahuja, 2014; Bhargav, Bhargav, Raghuram, & Garner, 2016; Fabio & Towey, 2018; Hari Chandra, Ramesh, & Nagendra, 2019), improving psychological and physical well-being and cognition (Tang *et alii*, 2007; Shonin & Van Gordon, 2016; Kreplin, Farias, & Brazil, 2018) resulting in why meditation is one of the most investigated topics of the twenty-first century. It has also been reported that meditation techniques can reduce mental disorders (Shonin & Van Gordon, 2016; Kreplin *et alii*, 2018). Several neuroimaging (EEG, MEG, and fMRI) investigations have found that meditation improves brain and cognitive processes (Niessing, *et alii* 2005; Pagnoni, Cekic, & Guo, 2008; Manna, *et alii,* 2010; Innes, Selfe, Khalsa, & Kandati, 2017; Scheibner, Bogler, Gleich, Haynes, & Bermpohl, 2017; Basso, McHale, Ende, Oberlin, & Suzuki, 2019). The rising global interest in these research' findings demonstrated the undeniable advantages of these techniques (Krishnakumar, Hamblin, & Lakshmanan, 2015). Interventions and therapies based on meditation are utilized to improve the well-being of clinical and non-clinical adult populations. Most meditation-related studies in psychology, neuroscience, and cognitive science examine the impact of meditation-based therapies on cognitive and brain processes, mental capacities, and well-being. Multiple domains, including mental and physical well-being (Grossman *et alii*, 2004), brain functions (Tang *et alii*, 2007), social skills and spiritual development (Wisner, Jones, & Gwin, 2010), have been shown

to benefit from meditation interventions, according to research (Sumter, Monk-Turner, & Turner, 2009).

Meditation requires selecting goal-relevant information from the multitude of sensory stimuli that flood the mind (Slagter *et alii*, 2007). Based on their objective, nature, procedure, and outcomes, two forms of meditation have been identified: focused attention meditation (FAM) and open monitoring meditation (OMM) (Raldiris, 2017). FAM involves the practise of concentrating on a selected perceptual object (e.g., breathing) (Raldiris, 2017). Studies indicate that FAM practises increase attention regulation abilities (Muye & Van Vugt, 2017), memory skills (Collins & Womsley, 2020), focus and creative skills (Muye & Van Vugt, 2017; Collins & Womsley, 2020; Lippelt, Hommel, & Colzato, 2014). It is also said that FAM practises cultivate the ability to identify mind wandering and separate the mind from it (Lutz, Slagter, Dunne, & Davidson, 2008; Malinowski, 2013; Ahuja, 2014; Cásedas, Pirruccio, Vadillo, y Lupiáñez, 2020). FAM techniques include meditation methods such as Samatha (Buddhist meditation), some forms of Zazen, Loving Kindness Meditation, Chakra Meditation, Kundalini Meditation, Sound Meditation, Mantra Meditation, Pranayama, Surat-Shabd-Yoga, and some forms of Qigong. OMM activities entail a broader attentional focus on a number of ongoing mind and bodily occurrences. Instead of focusing on a single object during meditation, this technique requires awareness and alertness towards ongoing occurrences and experiences (Raldiris, 2017). OMM practises promote psychological well-being and emotional regulation skills (Singleton *et alii*, 2014; Holzel, *et alii*, 2011). Interventions and programmes based on OMM are also beneficial in the treatment of psychological issues such as ADHD, attention disorders, depression, anxiety disorders, and stress (Hofmann, Sawyer, Witt, & Oh, 2010; Khoury, Sharma, Rush, & Fourrier, 2015; Lenz, Hall, & Smith, 2016). Taoist meditation, mindfulness meditation, loving kindness meditation, body scan meditation are among the various OMM (mindfulness-based) techniques. In recent times, numerous review investigations have been carried out regarding the impacts of interventions involving Focused Attention Meditation (FAM) and Open Monitoring Meditation (OMM) on working memory and its constituent components. Additionally, several randomized controlled trial studies have explored the influence of meditation on various aspects of working memory (Mrazek, Sarwar, Sekanina, Vasicek, & Roy, 2016; Jha *et alii* 2019; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010; Chambers *et alii*, 2008; Lippelt *et alii*, 2014; Jensen, Vangkilde, Frokjaer, & Hasselbalch, 2012; Manna *et alii* 2010; Tang *et alii* 2010; Slagter *et alii*, 2007). Individual studies have reported enhancement in working memory and core executive functions due to meditation interventions. There is a need for comprehensive systematic review and meta-analyses to examine mechanisms behind the benefits of meditation practices on working memory and VSWM.

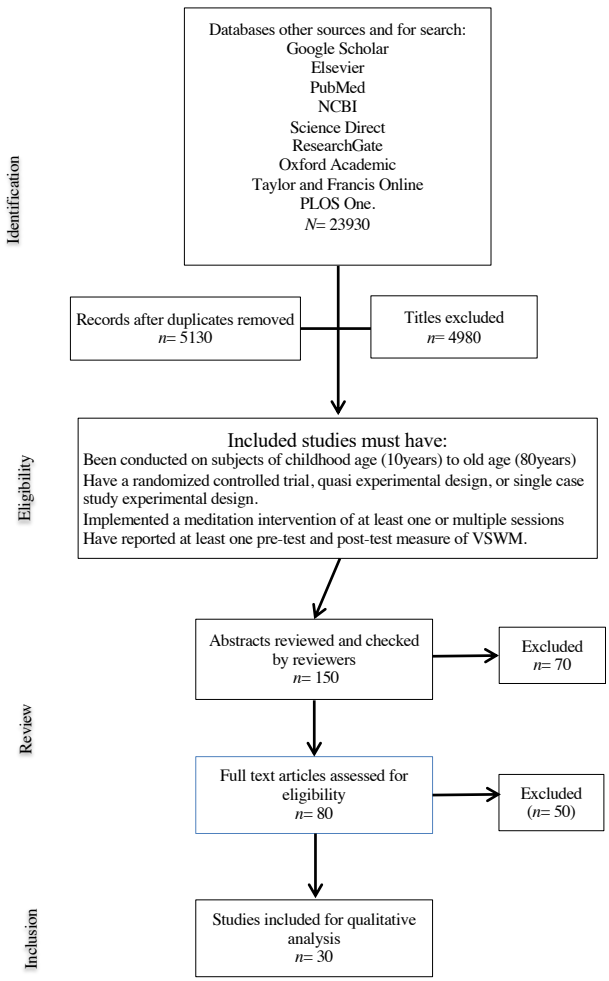
The present study reviews the findings of thirty studies on meditation interventions, providing a comprehensive overview of the current state of knowledge in the field. This systematic review aims to study the effect of the different types of meditation practices on VSWM. To address this objective, the study attempts to answer the following questions: What are the main effects of meditation-based interventions on VSWM? What are the various types of meditation practices included in the targeted interventions? What measures were used to assess the effectiveness of meditation interventions on VSWM? What methodologies were used in the reviewed studies?

Method

Study Search and Selection

A search for the review was conducted across various databases, including Google Scholar, Elsevier, PubMed, NCBI, Science Direct, ResearchGate, Frontiers, Oxford Academic, Taylor and Francis Online, and PLOS one. Openly accessible research articles related to meditation interventions and visuospatial working memory were searched. No language restrictions were placed while searching for articles. Additional research and articles included in the bibliography of selected studies were searched manually for references (Figure 1 shows the flow chart of the search technique).

A total of thirty randomized controlled trial studies along with case experimental study and neuroimaging studies were reviewed. Studies with control groups, active control groups and only experimental groups were included. Population, Intervention,



Comparison and Outcomes (PICO) framework was used for developing the inclusion criteria for the selection of research studies. The inclusion criteria were as follows:

This review encompassed studies that involved participants without any documented learning difficulties, mental health disorders, physical ailments, or cognitive impairments. Studies with participants from diverse ethnic backgrounds, genders, and socio-economic statuses were considered. The review incorporated both studies with individuals who were experienced in meditation and those who were not.

Randomized controlled trial studies were included in the review. In accordance with the core principles of systematic review methodology, the studies which clearly reported analysis and synthesis of results, were included (Gough, Thomas, & Oliver, 2012; Pawson *et alii*, 2005). The inclusion criteria for this review included analysing research that specifically investigated cognitive or physical strategies with the aim of enhancing visual-spatial working memory (VSWM). The potential influence resulting from any biases is carefully evaluated and openly disclosed.

The review comprises the studies that have reported the results of at least one assessment either before (pre-test) or after (post-test) the intervention of VSWM. Studies that investigated the relationship of VSWM with other cognitive abilities were also considered for the review. The included studies have reported on the near- or far-term effects, durability of effects, or any secondary outcomes of interventions that were measured. The research that has reported the effect of meditation on working memory was also included. The current review consists of neuroimaging studies related to both meditation interventions and VSWM.

Procedure

In the present review, studies examining the effects of meditation interventions on VSWM and working memory have been included. In these studies, interventions were conducted either by a teacher, or a healthcare professional or the researcher. The interventions carried out in various settings, including schools, clinics, centres providing professional meditation training, and research environments were included. The duration of short-term meditation intervention varied from 8 minutes to 30 minutes and duration of long-term meditation intervention varied from 2 weeks to 10 years. As VSWM is a subset of working memory (Baddeley & Hich, 2000), therefore the studies that have included working memory interventions, were also included in this review.

In the present review, data extraction process guided by the PICO (Population, Intervention, Comparison and, Outcomes) framework (Booth & Fry-Smith, 2004) was adopted (see Table 1). Population, study design, comparison and outcomes were extracted from each study, collected on MS Excel spread- sheet for review. Full-text articles were obtained for eligible and potential interventions. Data related to authors, publication year, content, population type, sample size, type of meditation interventions, study design, control intervention, control type, duration of intervention, measures and assessment tools used, assessment data, outcomes and conclusion, and risk of any kind of bias related to criteria was analysed for the review.

The risk of bias in the studies that were included is significant as a result of various methodological concerns, as assessed using Cochrane's risk-of-bias tool. None of the studies reported the use of power analysis for sample selection. Additionally, there was a lack of active control groups in four out of 30 reviewed studies and blinding in six out of 30 studies, which are important factors to consider in both meditation studies and visual-spatial working memory (VSWM) studies. Publication bias may have also

Table 1. Characteristics of the studies included

PICO Variable		Characteristics (*n*)
Population	Age Range	Children less that 10 years (3) Adolescents 11-17 years (3) Adults 18 years and above (24)
	Status	Experienced Meditators (*n*5) Non-Meditators (25)
Intervention	Intervention approach	FAMI (9) OMMI (21) WMI (10)
	Setting for intervention	School 6) University (10) Research Institution (4) Professional Meditation Training Centre (9) Old Age Home (1)
	Unit of delivery	Individual (8) Small Group (9) Whole Class (3) Combination of individual and control group (2)
	Duration	Single session (3) Multiple session (27) Total duration of MI ranged one day to 24 weeks Average total intervention duration 16 weeks
Comparison	Study design	Randomized Controlled Trials (30) Case series (1) Neuro-imaging Studies (5) Active control groups (26) No active control groups (4)
	Sampling	Sample size range across all included studies: 1-198
Outcomes	Measurement of VSWM	Standardized measure of VSWM (30) More than one aspect of WM along with VSWM measured (11)
	Measurement of transfer effects	Near-transfer (3) Far-transfer (4) Durability over time (4)

Notes: FAMI= Focused Attention Meditation Intervention; MI: Meditation Intervention; OMMI= Open Monitoring Meditation Intervention; WM= Working Memory; WMI= Working Memory Intervention; VSWM= Visuospatial Working Memory.

influenced the biases in this review. A comprehensive search for research articles was conducted, and preference was given to published articles that met the criteria. Furthermore, preference was given to selecting articles that were openly accessible for this review.

Studies were evaluated based on the use of standardized techniques for the evaluation of VSWM and other variables also. All the studies have included standardized tools for assessment. The current review examined the literature with respect to the employment of standardized measurements for visual-spatial working memory. Throughout the varied research studies, different tasks were used to measure VSWM. Some of these tasks include:

Memory Rotation Task (MRT; Shepard & Metzler, 1971): This task requires participants to mentally rotate objects or shapes to determine if they match a reference object. It assesses the capacity to mentally manipulate visual information in spatial dimensions.

Visual Memory Task (VMT; Kozhevnikov, Louchakova, Josipovic & Motes, 2009): This task likely evaluated participants' ability to remember and recall visual information, such as patterns or images, over a short periode.

Digit Span Task and *Spatial Span Task* (DST, SST; Young, Lee, Mireku, Sharma, & Kramer, 2021): These tasks are commonly used to assess short-term memory capacity. The digit span task involves repeating back a series of digits in the same order as presented, while the spatial span task requires repeating sequences of locations or positions.

Repeatable Battery for the Assessment of Neuropsychological Status (RBANS): This standardized battery consists of a set of neuropsychological tests designed to assess various cognitive functions, including memory, attention, and executive functions. Its use in a study likely provided a comprehensive evaluation of participants' cognitive abilities.

Simple Object Span Test and *Picture Span Test* (SOST, PST): Mentioned in a study by Pandya (2020), these tests likely involved participants recalling sequences of objects or pictures in a specific order, thus assessing their visual-spatial working memory capacity.

Data Analysis

Due to large variation in the included studies, and a number of factors including sample size, and use of non-standardized tools or measures, quantitative synthesis was conducted. Data of various components of interest was analysed addressing issues like age group of targeted population, statistical techniques used for hypothesis testing, components of meditation intervention and VSWM. First, the included studies were categorized based on the type of meditation interventions implemented. Next, results of all studies were examined in respect of primary outcomes, secondary outcomes, near and far effects of interventions. Last step involved the analysis of the results of those studies which have exhibited positive effects of interventions, strategies and training related to meditation, and VSWM.

Results

Thirty studies with 1854 participants were included in this review and their overview is provided in Table 2. These studies were conducted in thirteen different countries, with most being conducted in USA (6) followed by India (5), Netherlands (2), United Kingdom (2), Italy (1), Spain (2), Germany (2), Finland (3), Switzerland (1), South Korea (2), Norway (1), Iran (1), Thailand (1) and Australia (1). This gave insight into the effect of meditation-based interventions on VSWM in varied cultures across the world. Studies were arranged according to their publication date i.e., from 2005 to 2023. The review included thirty studies with participants ranging in age from 2 to 80 years (*M*age= 41 years). Fifteen studies focused on adults aged 18 to 80 years, including both experienced meditators and non-meditators. The age variation within each of these studies ranged from two to four years, except for one study which had a variation of 60 years (participants aged 20 to 80 years). Most studies (*n*= 24) involved students from kindergarten to university level. One study targeted female ADHD adolescents, while a case study involved a 64-year-old female participant. None of the studies included participants based on their socioeconomic status or ethnicity. Most of the selected studies (*n*= 27) were randomized controlled trials, and the majority (*n*= 25) employed an experimental design with an active control group. Only five studies used an experimental design without an active control group. In terms of outcome measurements, ten studies assessed different aspects of working memory, including visual-spatial working memory.

Meditation practices continue to gain attention in the scientific research community, particularly for their beneficial effect on brain, psychological and physical well-being, and cognition (Tang *et alii*, 2007; Shonin & Gordon, 2016; Kreplin, Farias, & Brazil, 2018). Most of the studies have concentrated on mindfulness meditation falling within the realm of open monitoring meditation techniques. Furthermore, sixteen studies encompassing a wide range of ages from 2 to 63 years, delved into the influence of open monitoring meditation approaches on various aspects of cognitive function, including VSWM, working memory, executive function, and overall cognitive performance. And found that mindfulness meditation improves VSWM, working memory and executive functioning. Young *et alii* (2021) in their study, reported the improved effect of mindfulness

Table 2. Overview of the studies reviewed.

Studies	*N*	Age (years)	Design & Data Analysis	Duration	Intervention	Assessment
Leite, 2023	38	18-24	NDA Two-way ANOVA	NDA	NDA	n-back Task
Uopasai, Bunterm, Tang, & Saksangawong, 2022	60	19-22	Quasi Experimental Pre-Post-test, active CG Two sample *t*-Test	15w	BM (Buddhist Anapanasati Meditation)	TWMBT
Stein *et alii*, 2022	83	11-18	ExG without Active CG, fMRI, Correlation	7M	Mindfulness Meditation	AAMS, n-Back task
Ahuja & Sriramamurti, 2021	59	*Ma* 34.33	Quasi Experimental ANOVA	20w	*Surat-shabd-yoga* Meditation (with training of *yogasanasi)*	DST; SST
Pragya *et alii*, 2021	142	*Ma 24.24*	RCT ExG with CG	8w	*Preksha Dhyana* Meditation	AWMA-2 SF, PANAS, CPT-3
Thompson *et alii*, 2021	70	18-63	RCT, ExG with active CG ANOVA	30m	MM	GLPT; PANAS.
Yamaya *et alii*, 2021	44	*Ma* 21.2	Randomised Block Design ANOVA, ANCOVA	NDA	Su-soku meditation	RST
Collins & Wamsley. 2020.	31	18-29	RCT ExG with no active CG, EEG Repeated Measures ANCOVA	5d	Breath-Focus Meditation	Icelandic-English word-pairing task
Das et alii, 2020	36	21- 25 *Ma* 22	RCT, ExG with active CG ANOVA	12w	BAM, MCM, and MV	BMSQ
Kang *et alii*, 2020	40	*Ma* 17.5	RCT, ExG with active CG, EEG ANOVA, *t*-Test, Chi Square Test.	3w	MMT (based on DahnMuDo)	Dual n-Back Task
Lane, 2020	61	19-68	Convenience sampling, SRQ ANOVA	NDA	MM	SMASS, CBTT
Manglani, Samimy, Schirda, Nicholas & Prakash, 2020	61	NDA	RCT ExG with Waitlist CG	4w	Mindfulness Meditation	SDMT, PASAT
Pandya, 2020	136	75-76	RCT, ExG with active CG ANOVA, MANOVA	3M	GMT	RBANS; SOST; PST.
Ritter & Álvarez, 2020	177	8- 11	RCT, ExG with active CG ANOVA	6w	MM (Mind Yeti program)	EFSQ
Wang *et alii*, 2020	45	18-65	RCT, ExG with active CG, EEG and ERP RMST, Topographic ANOVA, Post hoc Test, ERP analysis	2y	MM	n-Back task, Oddball, EEG

Notes: AAMS= Adult and Adolescent Mindfulness Scale; AB= Attentional Blink; active CG= active Control Group; AOST= Automated Operation Span Task; AWMA-2 = Alloway Working Memory Assessment short form; BAM= Breath Awareness Meditation; BDM= Buddhist Deity Meditation BM= Breathing Meditation; BMa= Backward Masking; BMSQ= Bull's Mental Skill Questionnaire; CAMM= Child Acceptance and Mindfulness Measure; CBTT= Corsi Block Tapping Task; CES-D= Center for Epidemiologic Studies Depression Scale; CG= Control Group; COWAT= Controlled Oral Word Association Test; CPT-3= Connor's Continuous Performance test 3rd editiond= days; DST= Digit Span Task; EEG= Electroencephalogram; EFSQ= Executive Function Student Questionnaire; EPT= Embedded Picture Test; ERP= Event-Related Potential; ExG= Experimental Group; F/B-DS= Forward/backward digit span (WAIS-R); FMI= Freiburg Mindfulness Inventory; FMT= Face Memory Task; GDS-SF= Geriatric Depression Scale – Short Form; GI= Guided Imagery; GLPT= Global-Local Processing Task; GMT= Guided Meditation Training; IG= Intervention Group; KIMS= Kentucky Inventory of Mindfulness Skills; LT= Listening Task; LTMI= Long Term Meditation Intervention; M= months; m= minutes; *Ma*= Mean Age in years; MAAS= Mindful Attention Awareness Scale; MCM= Mantra Chanting Meditation; MM= Mindfulness Meditation; MMT= Meditation Movement Taining; MTP= Mindfulness training program; MV= Meditation with Visualization; MRT= Mental Rotation Task; NDA= No Data Available; NEPSY= Neuropsychological Assessment; PANAS= Positive and Negative Affect Schedule; PASAT= Paced Auditory Serial Addition Test; PSC-10= Perceived Stress Scale 10; PST= Picture Span Test; PTT= Perspective Taking Test; RBANS= Repeatable Battery for Assessment of Neuropsychological Status; RCT= Randomized Controlled Trial; RMST= Root Mean Square Test; RST= Reading Span Test; RT= Recognition Task; SAI= State Anxiety Inventory; SCARED= Screen for Child Anxiety and Related Emotional Disorders SDMT= Symbol Digit Modalities Test; SLCT= Single Letter Cancellation Test; SLT= Style of Learning and Thinking; SMASS= State Mindful Attention Awareness Scale; SNAP-IV= Swanson, Nolan, and Pelham-IV; SOST= Simple Object Span Test; SRQ= Self-Reporting Questionnaire; SST= Spatial Span Task; ST= Stroop Test; SWMT= Sternberg WM Task; TMS= Toronto Mindfulness Scale; TMT= Trail Making Test; TWMBT= Thai Working Memory Computerize Battery Test; VMT= Visual Memory Task; VS= Visual Search; VSM= Visuospatial Memory Test; w= weeks; WAIS-R= Wechsler Adult Intelligence Scale-Revised; WAIS-IV= Wechsler Adult Intelligence Scale – Fourth Edition wCG= waitlist Control Group; WMS-III= Digit Span subscale of Wechsler Memory Scale; WMS-IV= Wechsler Memory Scale – Fourth Edition; y= years.

Table 2 (cont.). Overview of the studies reviewed.

Studies	*N*	Age (years)	Design & Data Analysis	Duration	Intervention	Assessment
Youngs *et alii*, 2020	90	18-25	RCT, ExG with active CG ANOVA, Kruskal- Wallis Test	8M	MM	LT; FMT.
Addison-Walker, 2019	24	6-8	RCT, IG with waitlist CG ANOVA	30d	GI and MM	DST; SST; WISC-V.
Lokka & Coltekin, 2019	81	20- 75	RCT, ExG with active CG Correlation	15m	NDA	VSM
Strickland & Selwyn, 2019	32	17-25 *Ma* 20.84	RCT, ExG with active CG *t*- Test	3M	MM	SLCT
Brock *et alii*, 2018	87	2- 8	RCT, ExG with active CG *t*-Test, ANOVA	24w	MM	NEPSY
Campillo *et alii*, 2018	50	22-62	ExG Mixed ANOVAs	30m	MTP based on Full Emotional Intelligence Program	PANAS; WMS-III; TMT
Fabio & Towey, 2018	36	41- 52	RCT, ExG with active CG, EEG Pearson's Correlation	6y	MM	ST; n- Back Test; VS; BMa; AB; SLT; KIMS.
Harne & Hiwale, 2018	23	18-22	RCT, ExG with no active CG with, EEG ANOVA	30m	OM Manta Meditation	NDA
Kiani, Hadianfard & Mitchell, 2017	30	13-15	ExG with Waitlist CG,	8w	Mindfulness Meditation	EF Laboratory Tasks, Self-Reported Emotion Dysregulation, SNAP-IV
Bailey *et alii*, 2016	58	36	ExG with CG ANOVA	6m	NDA	SWMT
Quach *et alii*, 2016	198	13- 15	RCT, ExG with active CG ANOVA	4w	MM	AOST; PSC-10; SCARED; CAMM.
Bloom, 2011	1	64	Case Study	4w	Mindfulness Meditation	MAAS, TMS, WAIS-IV, WMS-IV, GDS-SF
Van Vugt & Jha, 2011	29	21-70	ExG ANOVA	1m	Four Foundations of Mindfulness-Sathipattana Sutra	RT
Zeidan *et alii*, 2010	63	22-23	RCT, ExG with active CG ANOVA, MANOVA	4d	MM	FMI; SAI; CES-D; COWAT; F/B-DS; n-Back Task
Kozhevnikov *et alii*, 2009	71	37-42	RCT, ExG with active CG ANOVA	LTM 10y	BDM	MRT, VMT, EPT, PTT

Notes: AAMS= Adult and Adolescent Mindfulness Scale; AB= Attentional Blink; active CG= active Control Group; AOST= Automated Operation Span Task; AWMA-2 = Alloway Working Memory Assessment short form; BAM= Breath Awareness Meditation; BDM= Buddhist Deity Meditation BM= Breathing Meditation; BMa= Backward Masking; BMSQ= Bull's Mental Skill Questionnaire; CAMM= Child Acceptance and Mindfulness Measure; CBTT= Corsi Block Tapping Task; CES-D= Center for Epidemiologic Studies Depression Scale; CG= Control Group; COWAT= Controlled Oral Word Association Test; CPT-3= Connor's Continuous Performance test 3rd editiond= days; DST= Digit Span Task; EEG= Electroencephalogram; EFSQ= Executive Function Student Questionnaire; EPT= Embedded Picture Test; ERP= Event-Related Potential; ExG= Experimental Group; F/B-DS= Forward/backward digit span (WAIS-R); FMI= Freiburg Mindfulness Inventory; FMT= Face Memory Task; GDS-SF= Geriatric Depression Scale – Short Form; GI= Guided Imagery; GLPT= Global-Local Processing Task; GMT= Guided Meditation Training; IG= Intervention Group; KIMS= Kentucky Inventory of Mindfulness Skills; LT= Listening Task; LTMI= Long Term Meditation Intervention; M= months; m= minutes; *Ma*= Mean Age in years; MAAS= Mindful Attention Awareness Scale; MCM= Mantra Chanting Meditation; MM= Mindfulness Meditation; MMT= Meditation Movement Taining; MTP= Mindfulness training program; MV= Meditation with Visualization; MRT= Mental Rotation Task; NDA= No Data Available; NEPSY= Neuropsychological Assessment; PANAS= Positive and Negative Affect Schedule; PASAT= Paced Auditory Serial Addition Test; PSC-10= Perceived Stress Scale 10; PST= Picture Span Test; PTT= Perspective Taking Test; RBANS= Repeatable Battery for Assessment of Neuropsychological Status; RCT= Randomized Controlled Trial; RMST= Root Mean Square Test; RST= Reading Span Test; RT= Recognition Task; SAI= State Anxiety Inventory; SCARED= Screen for Child Anxiety and Related Emotional Disorders SDMT= Symbol Digit Modalities Test; SLCT= Single Letter Cancellation Test; SLT= Style of Learning and Thinking; SMASS= State Mindful Attention Awareness Scale; SNAP-IV= Swanson, Nolan, and Pelham-IV; SOST= Simple Object Span Test; SRQ= Self-Reporting Questionnaire; SST= Spatial Span Task; ST= Stroop Test; SWMT= Sternberg WM Task; TMS= Toronto Mindfulness Scale; TMT= Trail Making Test; TWMBT= Thai Working Memory Computerize Battery Test; VMT= Visual Memory Task; VS= Visual Search; VSM= Visuospatial Memory Test; w= weeks; WAIS-R= Wechsler Adult Intelligence Scale-Revised; WAIS-IV= Wechsler Adult Intelligence Scale – Fourth Edition wCG= waitlist Control Group; WMS-III= Digit Span subscale of Wechsler Memory Scale; WMS-IV= Wechsler Memory Scale -Fourth Edition; y= years.

meditation practice on visual short-term memory. Study investigated a single 8-minute-long mindfulness meditation session on visual short term memory tasks. 90 undergraduate participants were included in the study. Participants were divided into three different groups. Participants in the meditation group were presented with mindfulness breathing exercises and participants in the audiobook group with 8-minute-long audio instructions to follow and participants in the control group were asked to do anything they wished. It was found that a single session of mindfulness meditation helped in improving short term visual memory and working memory of the practitioners.

Another study by Thompson, Quigley, & Taylor (2020) explored the effectiveness of mindfulness meditation practice in influencing emotions and visual attention in adult participants. Post intervention emotional attention in meditators were found to be improved. The score of the tests reported that the meditation group receiving 10 minutes long mindfulness meditation training, performed better in PANAS than the control group. The reaction time in the global-local processing task of the meditators decreased significantly.

The study conducted by Strickland & Selwyn (2019) also reported the similar effect of mindfulness meditation intervention on cognitive functions. The study included undergraduate students receiving short term mindfulness meditation intervention of three minutes. Single Letter Cancellation Test (SLCT) was used to measure cognitive functions. Scores of the SLCT demonstrated that brief meditation practitioners have relatively fewer mistakes than the control group. The study reported that mindfulness meditation enhanced cognitive functioning.

Pandya (2020) compared an active control group to a group of older adults receiving a three-month meditation intervention that involved 30 minutes guided meditation in four living facilities of Mumbai and Pretoria. The main components of the meditation intervention included techniques for relaxation and slow breathing, as well as cultivating an inner state of mindful awareness. Each 30-minute guided session consisted of the following elements: (i) a period of prayer or silent sitting lasting 5 minutes, (ii) the Instant Relaxation Technique (IRT) performed while lying down, which involved isometric muscle contractions for 5 minutes, (iii) practicing the Tree posture (standing still) and focusing on centering oneself in that posture for 5 minutes, (iv) engaging in deep breathing while directing attention to the flow and rhythm of the breath for 10 minutes, and (v) concluding with a 5-minute Deep Relaxation Technique (DRT) performed while lying down. As for the assessment tools, the Repeatable Battery for Assessment of Neuropsychological Status (RBANS), the Simple Object Span Test (SOST) and the Picture Span Test (PST), were used to measure visual working memory of the participants. Post-test scores of the meditators were higher than the control group. Results suggested that meditators performed better on neuropsychological and visual working memory tests. Results of the study indicated that the impact of meditation varied based on demographic profile variables of certain participants (gender, socio-economic status, education, marital status), health related conditions, psychiatric diagnoses, number of meditation sessions attended, and self-practice.

In their study, Yamaya *et alii* (2021) investigated the impact of a single session of focused attention meditation (FAM) on the working memory capacity (WMC) of individuals who were novice to meditation. The study aimed to test the hypothesis that FAM could enhance WMC by stimulating the dorsolateral prefrontal cortex (DLPFC) through top-down attentional regulation. Participants were randomly assigned to either the FAM group or the control group. Assessments of working memory capacity (WMC)

were conducted both before and after each 15-minute meditation session. Functional near-infrared spectroscopy was used by the researchers to assess blood flow in the dorsolateral prefrontal cortex (DLPFC) and to measure the impact of top-down attentional regulation. The study's results demonstrated a significant enhancement in Working Memory Capacity (WMC) as a result of engaging in Focused Attention Meditation (FAM). Moreover, FAM practice induced activity in both the left and right dorsolateral prefrontal cortex (DLPFC) regions of the brain during the meditation session. Conversely, the control group exhibited a decline in working memory capacity (WMC) following the session. Notably, no activity was observed in either hemisphere of the dorsolateral prefrontal cortex (DLPFC) during the intervention. These research findings suggest that the adoption of Focused Attention Meditation (FAM), which involves the application of top-down attentional control, activates both the bilateral dorsolateral prefrontal cortex (DLPFC) and enhances working memory capacity in individuals who are new to meditation.

All the studies used standardized tests for the assessment of VSWM, working memory and executive functions. These studies employed a variety of statistical techniques like ANOVA, correlation and regression, factor analysis and other additional techniques like multilevel modeling.

This review has included studies that have analysed the effectiveness of various kinds of meditation practices on executive functioning and its components. Out of thirty reviewed studies, a total of twenty-one have examined the effect of mindfulness meditation on various cognitive functions. The age range of participants in mindfulness meditation intervention varied from 2 to 76 year.

Ten open monitoring studies have been conducted on adults aged between 18 to 76 years. Five open monitoring meditation studies have included children aged between 2 to 13 years (Thompson, Quigley & Taylor, 2020; Strickland & Selwyn, 2019; Fabio & Towey, 2018; Zeidan, Johnson, Diamond, David & Goolkasian, 2010); including executive functioning (Kiani, Hadianfard & Mitchell, 2017), working memory (Stein, Bray, MacMaster, Tomfohr-Madsen, & Kopala-Sibley, 2022; Bailey *et alii*, 2020; Manglani, Samimy, Schirda, Nicholas & Prakash, 2020; Pandya, 2020; Wang *et alii*, 2020; Addison-Walker, 2019; Jha *et alii*, 2019; Quach, Mano, & Alexander, 2016; Bloom, 2011; Van Vugt & Jha, 2011), visuospatial working memory (Young *et alii*, 2021; Lane, 2020; Brock, Murrah, Cottone, Mashburn, & Grissmer, 2018; Campillo, Ricarte, Ros, Nieto, & Latorre., 2018; Bloom, 2011).

Nine studies have employed various types of focused attention meditation practices like Surat-Shabd-Yoga meditation (Ahuja & Sriramamurti, 2021), Buddhist deity meditation (Kozhevnikov, Louchakova, Josipovic, & Motes, 2009), Mantra Meditation (Das *et alii*, 2020; Harne, & Hiwale, 2018), Meditation movement training based on the practice of DahnMuDo (Kang *et alii*, 2020), Breathing meditation based on Buddhist Anapanasati Meditation (Uopasai, Bunterm, Tang, & Saksangawong, 2022) Su-soku meditation (Yamaya *et alii*, 2021), Breath- focus meditation (Collins, & Wamsley, 2020). and one study by Pragya *et alii* (2021) has studied the effect of combination of two Preksha Dhyana practices including a sound-based technique (Mahapran) and visual colour-based technique (Lesya dhyana) on short-term working memory. Nine focused attention meditation intervention studies (Harne & Hiwale 2018; Kozhevnikov, Louchakova, Josipovic, & Motes 2009; Collins, & Wamsley, 2020; Das *et alii* 2020; Kang *et alii* 2020; Ahuja & Sriramamurti 2021; Pragya *et alii*, 2021;Yamaya *et alii* 2021; Uopasai, Bunterm, Tang, & Saksangawong 2022) included participants aged between 16 to 80 years.

The meditation interventions cover a wide range of durations, from as short as three minutes to as long as 10 years. These interventions were conducted for various timeframes, including three minutes (Strickland & Selwyn, 2019), eight minutes (Youngs, *et alii*, 2020), 15 minutes (Lokka & Colketin, 2019), and 30 minutes (Campillo, *et alii*, 2018; Thompson *et alii*, 2020), all of which yielded positive results in relation to their impact on VSWM. There was a single study that provided a meditation intervention for only four days (Zeidan, *et alii*, 2010), which had a slightly longer duration compared to the very short-term interventions, and it also demonstrated positive effects on VSWM.

Moreover, short-term interventions ranging from three weeks to eight weeks (Addison-Walker, 2019; Kang, *et alii*, 2020; Kiani *et alii*, 2017; Quach *et alii*, 2015; Ritter & Álvarez, 2020; Van Vugt & Jha, 2011) showed significant improvements in VSWM. On the other hand, there were six long-term interventions, lasting from 12 weeks to 24 weeks (Ahuja & Sriramamurti, 2021; Bailey *et alii*, 2016; Brock *et alii*, 2018; Das *et alii*, 2020; Uopasai, Bunterm, Tang, & Saksangawong, 2022). In addition, researchers also conducted very long-term interventions spanning two years (Wang *et alii*, 2020), six years (Fabio & Towey, 2018), and 10 years (Kozhevnikov *et alii*, 2009), and these extended interventions also had positive effects on VSWM.

Discussion

This review included 30 independent randomized controlled trial studies, following detailed examination of each study to make certain that there were no overlaps between studies. The review was conducted with the aim to provide a comprehensive overview of the current information relating to the interlink between meditation interventions and VSWM. The included studies adopted a variety of study designs, involved different meditation interventions, and comprised a variety of assessment tools for the measurement of VSWM. The purpose of this review was to systematically examine the effectiveness of meditation interventions on VSWM. The first main objective of this review was to elucidate the benefits to VSWM resulting from meditation practices. Studies on meditation practices that tapped on VSWM, visual attention, working memory, executive functions, mental skills, and cognitive functions were assessed. The present review analysed all the studies based on the PICO (Population, Intervention, Comparison and, Outcomes) framework (Booth & Fry-Smith, 2004). Research findings indicate that meditation interventions have a beneficial impact on visuospatial working memory (VSWM). Both short-term and long-term meditation practices were found to enhance VSWM and other cognitive abilities (Ahuja & Sriramamurti, 2021; Bailey *et alii*, 2016; Brock et alii, 2018; Campillo et alii, 2018; Das *et alii*, 2020; Lokka & Colketin, 2019; Uopasai, Bunterm, Tang, & Saksangawong 2022; Thompson *et alii*, 2020; Youngs *et alii*, 2020); however, long-term meditation was associated with more sustained effects on cognitive processes and brain function (Fabio & Towey, 2018; Luders, Toga, Lepore, & Gaser, 2009). Similar cognitive benefits were observed in a study by Kiani *et alii* (2017), which reported that mindfulness meditation improved executive functions and reduced emotional dysregulation in female adolescents with ADHD. In recent years, mindfulness meditation has gained widespread recognition, largely due to its roots in ancient contemplative traditions and its integration into contemporary psychological and wellness practices. It has demonstrated potential as a complementary approach in clinical settings alongside traditional therapies.

Given its broad applicability and cognitive benefits, mindfulness meditation remains a key area of research across multiple disciplines, including psychology, neuroscience, medicine, education, and workplace management. Some researchers have also studied the effect of other focused attention meditation practices. Kozhevnikov *et alii* (2009) examined the effects of Deity Yoga meditation, a focused attention practice, on mental imagery abilities in Buddhist monks with advanced visualization skills. Participants were categorized into two groups: Deity Yoga, which involved concentrated focus on an internal visual image, and Open Presence, characterized by distributed attention without a fixed object. Both groups completed computerized mental-imagery tasks before and after meditation, with results compared to control groups engaged in resting or visuospatial tasks. While no baseline differences in imagery skills were found between meditators and non-meditators, meditators demonstrated significantly superior performance in imagery and spatial tasks. These findings suggest that meditation enhances access to higher visuospatial resources.

The effect of Surat-Shabd-Yoga meditation, which comes under the category of focused attention meditation practices on VSWM, was positive (Ahuja & Sriramamurti, 2021). Study reported changes in VSWM and verbal working memory capacity in different stages of the Surat-Shabd-Yoga meditation training during the 20 weeks practice. The meditation process involves three stages: In the initial stage, one practices mantra meditation. In the second stage, contemplation of form and mantra meditation are combined. Finally, in the third stage, simultaneous contemplation of form, sound, and mantra meditation takes place. The study included four strata: novice meditators with no prior experience of the meditation practice, intermediate meditators or first initiates who had acquired the training of contemplation form of Surat-Shabd-Yoga meditation, advanced meditators or second initiates who had acquired the training of contemplation form and sound, and active control group. Participants were also provided the training of yogasanas along with training of Surat-Shabd-Yoga meditation.

The meditation practice changes brain activities and improves cognitive functions of adults (Kang *et alii*, 2020). The study compared a meditative movement group and control group consisting of young adults. Experimental groups were given the training of DahnMuDo under the supervision of an expert. The training program consisted of three exercises performed with closed eyes. The initial exercise, called Single Leg Stance (Dong-Nip-Bo), required extending the right arm 90° to the front while holding the left foot to maintain balance. The second exercise mirrored the first but in the opposite direction. The final exercise, known as Horse Stance (Ki-Ma-Bo), involved bending the knees as if sitting on a chair after spreading the legs shoulder-width apart and sustaining the posture. This training program is part of a supplementary after-school class in Korea aimed at fostering the holistic development of students' minds and bodies. Participants were instructed to perform each step for 3 minutes. Those in the experimental group were asked to engage in the training program twice daily, spending 9 minutes each time, for a duration of 3 weeks. Concurrently, participants were encouraged to maintain a clear or calm state of mind while regulating their breathing. Participants in the control group were seated and instructed to relax during the corresponding period. Results of the study suggested that the meditative movement group performed better in working memory tasks, which was related to brain activities of the participants which were similar to the results of Mrazek *et alii* (2016), -i.e., mindfulness meditation improved working memory capacity while reducing mind wandering.

Several EEG studies have identified various neural activities indicating improved attentional processing in meditators (Bailey *et alii*, 2016; Fabio & Towey, 2018; Kang *et alii*, 2020). Event-related potential (ERP) studies have explored the effects of meditation on working memory by analysing neural responses associated with cognitive processing. ERP Studies have also reported prolonged N200 and P300 ERP amplitudes in participants post meditation, which reflects improved attentional resource allocation, cognitive control and working memory updating (Bailey *et alii*, 2016; Wang *et alii*, 2020). These studies suggest that meditation enhances working memory, selective attention by reducing distractions, and improving executive control.

Evidence reported that meditation interventions and visuospatial working memory showed the same brain region activations such as prefrontal cortex, parietal cortex, ACC and parietal cortex, brain regions that are associated with working memory and executive control (Bailey *et alii*, 2016; Kang *et alii*, 2020). An fMRI investigation conducted by Short *et alii* (2010) also reported a similar effect of meditation on attention regulation and found increased attentional ability. The brain regions, Dorsolateral Prefrontal Cortex (DLPC) and Anterior Cingulate Cortex (ACC) were more associated with attention. During functional magnetic resonance imaging DLPC and ACC are found to be highly activated in meditation practitioners. A study by Pagnoni *et alii* (2008) discovered that focused attention meditation practice results in strong activity signals in brain regions associated with attention, including the inferior parietal lobule, superior temporal gyrus, cingulate cortex, caudate, and lateral prefrontal cortex. According to EEG studies on open monitoring meditation practices, the fronto-parietal region of the brain, which is linked to attention and metacognitive awareness, is highly activated (Gazzaniga, 1995; Manna *et alii*, 2010; Scheibner *et alii*, 2017). In a neuroimaging investigation, Collette, Hogge, Salmon, & Van der Linden (2005) did a functional MRI analysis to explore the neural activations of executive functioning. The study reported that Prefrontal Cortex (PFC) and Parietal Cortex were mainly involved in working memory functions. Findings of this investigation were also supported by the findings of Koenigs, Barbey, Postle, & Grafman (2009). Nee *et alii* (2013) reported that with PFC, spatial working memory tasks also activates the parietal cortex bilaterally, with some lateralization in the direction of the right hemisphere of the brain. Study found that most part of the cerebellum is activated working memory.

Meditation-based interventions serve as effective tools for enhancing cognitive function and mental well-being across various populations. Meditation based therapies have shown promise in improving memory and attention in individuals with cognitive impairments, anxiety, depression, and ADHD (Das *et alii*, 2020; Hofmann *et alii*, 2015; Lenz, Hall, Smith, 2016; Lippelt *et alii*, 2014; Moreno *et alii*, 2023; Moye & Van Vugt 2017). Mindfulness-based cognitive therapy (MBCT) and mindfulness-based stress reduction (MBSR) are widely recognized for their effectiveness in mental health treatment. In educational settings, integrating meditation into school curricula can enhance students' focus, memory retention, and overall cognitive performance. Furthermore, meditation training supports stress management and strengthens executive functions, potentially leading to improved academic outcomes. Several studies have suggested that long-term meditation practice may help slow age-related memory decline (Ahuja & Sriramamurti, 2021; Pandya, 2020; Van Vugt & Jha, 2011).

The present review analysed the available literature to investigate the effect of different types of meditation interventions on VSWM. The study reviewed available randomized controlled trial studies to find out the effect of meditation interventions on

VSWM. However, the outcome of the measurements used, and other evidence collected from the reviewed studies suggested that meditation interventions have significant effects on VSWM. Based on the evidence, a positive relationship between meditation interventions and visuospatial working memory is evident. The review also gave insight into the types of meditation interventions used; duration of the interventions, intervention approach assessment tools used, age group targeted, and examination of the effect of meditation interventions on VSWM, methodology and study design.

While this review provides strong evidence for the benefits of meditation interventions on VSWM, several gaps remain, including the potential for bias in individual studies due to sample size, lack of control over confounding variables, absence of an active control group, and other methodological problems. In the absence of a clear knowledge of methodology and theoretical framework in some studies, the evidence collected for this study is similarly limited. A lack of a solid theoretical framework may result in ambiguous predictions and findings regarding the effect of an intervention or training and its influence on the outcome of the study's measurement. Four researches did not have an active control group. No incorporation of an active control group could infer that the benefits of meditation interventions are also attributable to other characteristics that may differ from the experimental group or the passive group (Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015). In some studies, training tasks and evaluation results were not precisely described.

From both fundamental and applied perspectives, many questions related to the utility of different meditation practices are still unanswered. However, researchers are investigating the effect of different meditation interventions on cognitive and non-cognitive abilities. The review offers evidence of the effectiveness of different meditation training on VSWM and other components of working memory. Additional research can be performed to examine the mechanisms underlying the therapies that led to the improvement of VSWM. There is a need for additional research on beginning meditators. It is possible to compare the effects of novice and experienced meditators in the studies. Additionally, the comparative effects of various meditation practices might be investigated. Only a few longitudinal researches on meditation therapies are known in the scientific literature. Very few studies have reported the long-term impact and durability of therapies. To fill up the gaps left by earlier study, additional investigation is necessary. Future hypothesis-driven studies must provide a clear theoretical and practical account of how and why meditation therapies affect VSWM and other cognitive capacities.

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