A systematic exploratory review investigating the relationship between working memory and emotion regulation: implications for working memory training

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Abstract

Working memory training (WM-T), as an intervention strategy to improve emotion regulation (ER), has become popular in cognitive psychology. However, it poses many different challenges for researchers, and far-transfer effects on subsequent ER have been debated. This systematic exploratory review investigates how the WM-ER dyad is implicated in WM-T as an intervention strategy for improving ER. Systematic review protocols were followed for the selection of studies investigating the relationship between WM and ER, and WM-T to improve ER. An electronic database search following the PRISMA statement was conducted in which 15 studies were considered eligible. The studies were assessed for quality control using an adapted Critical Appraisal Skills Programme (CASP) tool for quantitative studies. Studies were analysed using the population, variables, and outcomes (PVO) strategy for systematic exploratory reviews. Five studies included psychological disorders and one study used brain imaging. From a neural perspective, the coupling of the prefrontal cortex and the anterior cingulate cortex over the amygdala was involved in the WM-ER dyad. Although there was a lack of evidence of far-transfer effects of WM-T to improve ER, the mechanisms of reward-enhancing effects in WM-T, as well as dopamine release (involved in brain-reward circuitry), should be explored further. This will allow researchers to re-evaluate the direction that the investigation is taking. More concerningly, there is a need for quality control in WM-T studies due to several studies acking sufficient attention to ethical considerations standardisation. Future WM-T studies must ensure that research is founded on quality evidence.

Keywords: Emotion regulation, stress, systematic reviews, working memory, working memory training

Working memory (WM) assists us in not only temporarily retaining new information but also manipulating incoming information for problem-solving and other mentally challenging activities in our everyday lives (Baddeley, 1992). WM is involved in the intellectual processes of the brain (Ahmad et al., 2016) including keeping and updating information in mind (Friedman & Miyake, 2017; Hofmann et al., 2012). The function of *updating* in WM assists individuals to maintain newly accessed information and shield it from distraction (Hofmann et al., 2012). This ability coupled with emotional content later became known as *emotional working memory* (eWM) which includes the updating of emotional stimuli into WM (Pe et al., 2013). Young adults who have grown up with technology are among the heaviest media multitaskers in learning environments and there is evidence that WM is of central importance to effective multitasking (Pollard & Courage, 2017). However, poor WM can increase the chances of depression (Peckham et al., 2019) and lead to mood, anxiety, and psychotic disorders (Barkus, 2020). With compromised WM, individuals may feel unable to regulate their emotions, and poor or maladaptive emotion regulation (ER) strategies could be selected (Barkus, 2020; Schmeichel et al., 2008). Individuals may start to feel like they are losing control which may evoke a negative emotional reaction or lead to aggressive behaviour (Baron et al., 2009).

ER attempts to improve experience, expression, or the duration of an emotional reaction (Schmeichel et al., 2008) and serves as an internal mechanism to avoid inappropriate aggression when cognitive resources are 'stretched' (Baron et al., 2009). Spontaneous ER, or implicit ER, is automatic and related to the attentional ability to successfully carry out goal-directed behaviour despite distractions (Klumpp et al., 2017). Neuroimaging studies reveal activation of the prefrontal regions of the brain associated with WM while using ER strategies, such as reframing or reappraisal (Evans et al., 2016). Reappraisal is an adaptive explicit (non-spontaneous) form of ER (Klumpp et al., 2017), whereby depressed individuals are discouraged from their negative thoughts and rather encouraged to think differently (Schmeichel & Demaree, 2010). Reappraisal is the most adaptive strategy of effortful ER (Zhang et al., 2018).

Working memory training to improve emotion regulation

Working memory training (WM-T), as an intervention strategy to improve ER, has been found to have methodological shortcomings (disparate cognitive paradigms), a lack of theory-driven, systematic approaches (Von Bastian & Oberauer, 2013), publication bias (Pappa et al., 2020), and multifaceted relationships between the updating and attention orientation functions in WM and ER (Xui et al., 2018). Training outcomes on untrained tasks following WM-T have been debated with some researchers stating that far-transfer effects (i.e., improvements in ER) are zero (Pappa et al., 2020), while others speculate that far-transfer effects are possible due to the cognitive and neural overlap between WM and ER (Barkus, 2020). The neural underpinnings between WM and ER were researched to investigate how WM-T would affect the neural system that will improve ER.

Sufficient prefrontal control of the limbic system (particularly the amygdala) is crucial for successful ER as the medial prefrontal and cingulate cortices regulate the amygdala (Zhang et al., 2018). This control reduces negative emotions and stress, as frontolimbic networks support ER, helping to guard against aggression and supporting cognitive and social aptitude (Wolf et al., 2018). Furthermore, oxytocin has been shown to increase the coupling between the amygdala with medial prefrontal regions (Eckstein et al., 2017). Researchers using functional magnetic resonance imaging (fMRI) scanning have found that the neural circuitry of ER includes the orbitofrontal cortex, lateral and medial prefrontal cortex, the anterior cingulate cortex, and the amygdala and that deficits in central nervous serotonin (5-HT) release impairs cognitive control of emotions (Wolf et al., 2018). When neurotransmitters such as medial prefrontal N-acetylaspartate and glutamate decrease, emotional dysregulation is thought to increase (Kang et al., 2021). Moreover, the striatum controls the access of information from the lateral PFC to WM, termed 'input gating' (Lorenc et al., 2021, p. 236). Dopaminergic release in frontostriatal circuitry is crucial for WM functioning (D'Esposito & Postle, 2014) and neurons in the nigrostriatal system release to the striatum and are involved in motivation (Takeuchi et al., 2015). Furthermore, the projection of noradrenaline, serotonin, and dopamine energises the actions across systems (Greenberg, 2006).

Aims and objectives

This systematic exploratory review draws upon the extant literature on the WM-ER dyad and the practical motivations of WM-T to improve ER found in empirical studies. The systematic exploratory review aims to identify and understand the WM-ER dyad and its implications for WM-T. To achieve this, the systematic exploratory review is governed by the following two objectives:

Objective 1. To investigate the relationship between WM and ER whereby WM is the independent variable (IV) and ER is the dependent variable (DV).

Objective 2. To investigate the WM-ER dyad and how it is implicated in WM-T studies whereby: WM-T studies are selected through a systematic review process and analyzed using a PVO strategy.

The objectives are part and parcel of the exposition of the WM-ER dyad which is implicated in WM-T against the dearth of existing empirical studies using WM-T for ER outcomes.

Justification for the research method

The systematic exploratory review comprises two methods, systematic and exploratory, thus benefitting from their empirical and theoretical perspectives. Although systematic reviews are robust, they are not always the most suitable strategy (Snyder, 2019) because there needs to be a balance between exploratory and systematic viewpoints, and preferably, any study should have a combination of both (Pertl & Hevey, 2010). The systematic review enabled the researcher to address the research question with more strength than a single empirical study would have (Snyder, 2019). The meticulous method of a systematic review has enabled researchers to progress faster, which is especially relevant in South Africa and Africa because access to knowledge is challenging owing to a lack of technology and funding (Laher & Hassem, 2020). Due to the advantage of following planned, clear, and inclusive protocols (Laher & Hassem, 2020), the systematic review can determine the efficacy across studies and direct future studies to demonstrate the desired effect (Snyder, 2019). The exploratory review enabled the authors to identify research gaps and patterns in the extant literature concerning the WM-ER dyad and WM-T to improve ER and assess how effectively the theories fit the data derived from selected empirical studies in the systematic review. As other reviews and meta-analyses have been conducted regarding the efficacy of WM-T, this study provides novel insights regarding the relationship between WM and ER implicated in WM-T to improve ER.

Method

The systematic review of sampled publications complied with the eight stages of a systematic review adopted by Uman (2011).

Guiding question

How is the WM-ER dyad implicated in WM-T as an intervention strategy for improving ER?

Inclusion and exclusion criteria

The search was conducted from January to August 2021. Published and peer-reviewed articles from 2002 onwards were selected from databases for the systematic review. Patient samples (anxiety, depression, and bipolar I disorder), as well as healthy samples, were included. Articles were inclusive of different study designs used in trials. Both genders were included as well as participants of all races, ethnic groups, and countries of the given study. The selection of studies did not focus on (a) interference resolution as the input into WM, (b) intelligence, and (c) academic performance as variables concerning WM. The relationship between WM and academic performance was not considered because the study aimed to investigate the relationship between WM and ER, irrespective of academic performance and other factors that improve academic performance, such as economic status, for example, could influence the results. The samples did not include children (i.e., participants under 18 years of age) or older adults (i.e., participants older than 60 years). Systematic review and meta-analysis studies were excluded from the selection of eligible studies, as empirical studies were preferred.

Protocol

The process of conducting the systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (see Figure 1). A total of 15 studies were found to be eligible for this review.

Quality assessment

The adapted Critical Appraisal Skills Programme (CASP) tool for quantitative articles from Laher and Hassem (2020) was used to assess the quality of each study (see Supplemental Annexure 1).

The selected studies had scores between seven and 11, which indicated that the overall quality of the studies was satisfactory (see Table 1).

Ethical considerations

Ethics clearance for the study was obtained from the University of Pretoria (HUM026/0820). The sources were obtained from academic journals and legal databases and all the references were listed. The co-researcher assisted with the selection strategy process by reviewing the studies for selection after the screening, thereby reducing bias.

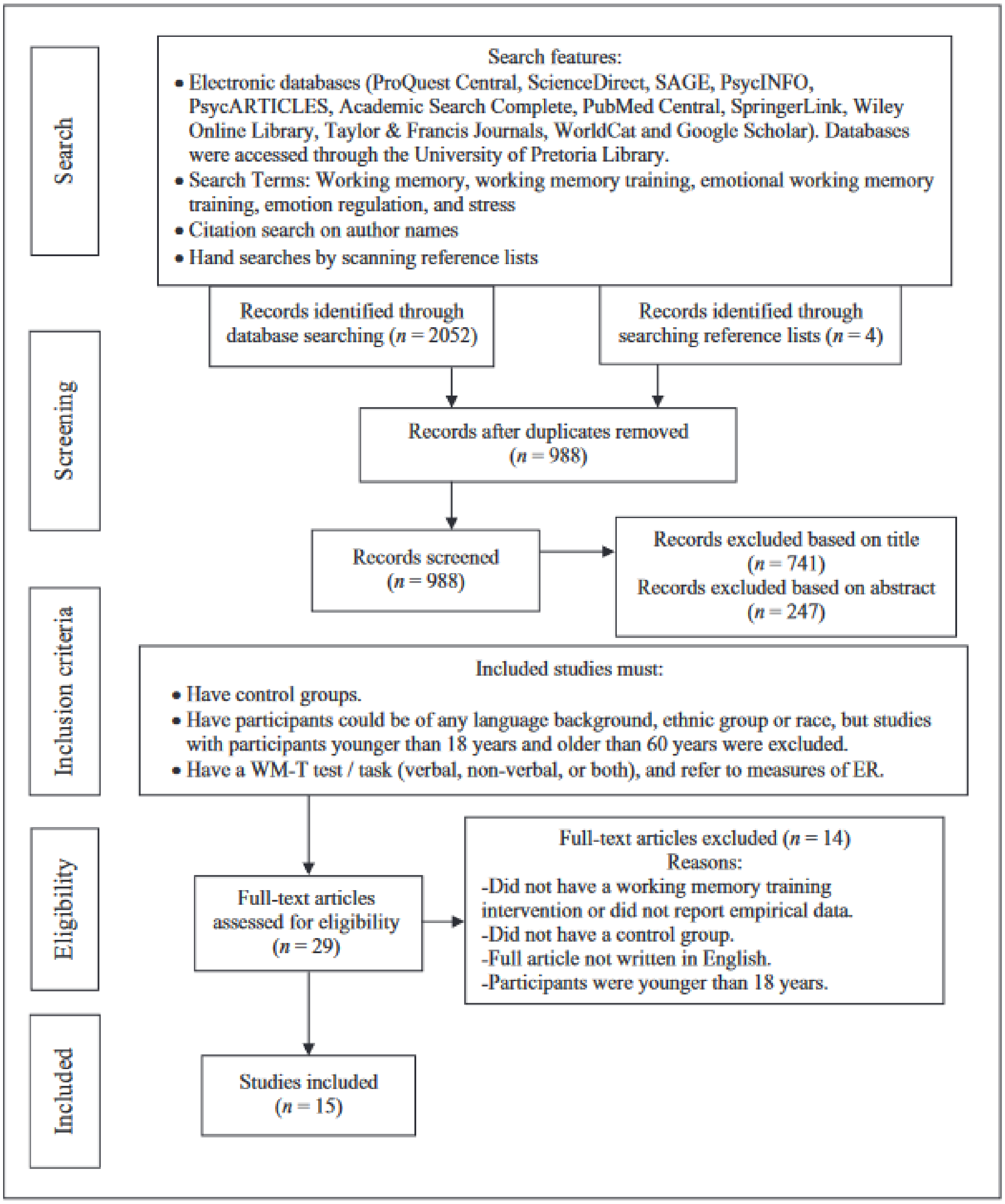

Figure 1. The selection of working memory training studies following the PRISMA flow diagram

Table 1. Analysis of the potential risk of bias and quality of the eligible articles.

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Total
Schmeichel et al.	✓	✓	✓	–	✓	✓	–	✓	✓	–	✓	8
Schmeichel & Demaree	✓	✓	✓	–	✓	✓	–	✓	✓	–	✓	8
Dubert et al.	✓	✓	✓	✓	✓	✓	–	✓	✓	✓	✓	10
Rutherford et al.	✓	✓	✓	–	✓	✓	✓	✓	✓	–	✓	9
Yoon et al.	✓	✓	✓	✓	–	✓	–	✓	✓	✓	✓	9
Peckham et al.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	11
Bemath et al.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	11
Xui, Wu, et al.	✓	✓	–	–	✓	✓	✓	✓	✓	–	✓	8
Wang et al.	✓	✓	✓	–	✓	✓	✓	–	✓	–	–	7
Long et al.	✓	✓	✓	–	✓	✓	✓	✓	✓	✓	✓	10
Deng et al.	✓	✓	–	–	✓	✓	✓	✓	✓	✓	✓	9
Pe et al.	✓	✓	✓	✓	✓	✓	–	✓	✓	✓	✓	10
Schweizer et al.	✓	✓	–	✓	✓	✓	–	✓	✓	–	✓	8
Xui, Zhou, et al.	✓	✓	–	✓	✓	✓	✓	✓	✓	–	✓	9
Pan et al.	✓	✓	–	✓	✓	✓	–	✓	✓	–	✓	8

Source: Grade: ✓ (yes, 1 point), – (no, 0 points). Checklist adapted from Laher & Hassem (2020).

Analysis

For the analysis of the selected studies, attention was drawn to the PVO strategy for systematic exploratory reviews (Silva et al., 2017). The PVO strategy frames the research question and informs the analysis of the population (P), variables (V), and outcomes (O) of the studies. The 15 eligible studies were organised and separated into three categories to simplify analysis and obviate confusion regarding WM and ER and the outcomes of WM-T on ER. The studies were placed in chronological order and categorised as follows: Table 2 includes seven studies investigating the relationship between WM and ER. Table 3 includes four studies investigating WM-T for ER outcomes and Table 4 includes four studies that use eWM-T for ER outcomes.

The 15 studies included a total of 952 (618 female and 334 male) participants (see Table 5). In terms of the selection criteria of the present study, as indicated, the researchers chose to include adult participants between the ages of 18 and 60 years. The researchers made an exception with one study which had an age range of 17 to 24 years (M_{age} = 20). For the analysis, the researchers divided the age of participants into two cohorts, 18 to 26 years old, and 27 to 44 years old. None of the studies included participants aged 45 years and older. The characteristics of the participants were divided into four groups (university students, mothers, and drug abstainers; those not specified were grouped as the general public) for analysis.

WM and ER as variables featured in all 15 studies. The operationalisation and measurement of WM and ER found in the selected studies further relate to the WM-ER dyad

Table 2. List of studies investigating the relationship between working memory and emotion regulation.

Name of author(s)	Year	Country of study	Sample	Participant age range	Training measures and tasks	Title of study
Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A.	2008	United States	(Study 4) 63 Participants 38 Females 25 Males	Undergraduate students Ages 18 to 23	Study 4: Operation Span task (OSPAN) University of Wales Institute of Science and Technology Mood Adjective Checklist (UWIST Mood Adjective Checklist)	Working memory capacity and the self-regulation of emotional expression and experience.
Schmeichel, B. J., & Demaree, H. A.	2010	United States	102 Participants 77 Females 25 Males	Undergraduate students	Positive and Negative Affective schedules (PANAS) Operation Span task (OSPAN) Over-Claiming Questionnaire (OCQ)	Working memory capacity and spontaneous emotion regulation: High capacity predicts self-enhancement in response to negative feedback.
Dubert, C. J., Schumacher, A. M., Locker, L., Gutierrez, A. P., & Barnes, V. A.	2016	United States	80 Participants 72 Females 8 Males	Undergraduate students $M_{Age} = 23$ years	Mindful Attention Awareness Scale (MAAS) Emotion Regulation Questionnaire (ERQ) Automated Operation Span task (AOSPAN)	Mindfulness and emotion regulation among nursing students: Investigating the mediation effect of working memory capacity.
Rutherford, H. J. V., Booth, C. R., Crowley, M. J., & Mayes, L.C.	2016	United States	41 Participants 41 Females (all mothers) Married: 9 Single: 29 Separated: 1 Not reported: 2	$M_{Age} = 28$ years	Corsi Block Tapping Test (CBTT) Wechsler Adult Intelligence Scale IV Backward Digital Span task (WAIS-IV BDS) Emotion Regulation Questionnaire (ERQ) Difficulties in Emotion Regulation Scale (DERS)	Investigating the relationship between working memory and emotion regulation in mothers.
Yoon, K. L., LeMoult, J., Hamedani, A., & McCabe, R.	2018	Canada	45 Participants 29 Females 15 Males	$M_{Age} = 29$ years	Reading Span task (RSpan) Trier Social Stress Test (TSST) Beck-Depression Inventory-II (BDI-II) Penn State Worry Questionnaire (PSWQ) Ruminative Response Scale (RRS)	Working memory capacity and spontaneous emotion regulation in generalised anxiety disorder.
Peckham, A. D., Johnson, S. L., & Swerdlow, B. A.	2019	United States	59 Participants 31 Females 28 Males	$M_{Age} = 28$ years	Structured Clinical Interview for DSM-IV (SCID-IV) Young Mania Rating Scale (YMRS) Modified Hamilton Rating Scale for Depression (MHRSD) Emotion Regulation Questionnaire (ERQ) Ruminative Responses Scale-Brooding Subscale (RRS) Wechsler Adult Intelligence Scale IV Backward Digital Span task (WAIS-IV BDS)	Working memory interacts with emotion regulation to predict symptoms of mania.
Bemath, N., Cockcroft, K., & Theron, L.	2020	South Africa	38 Participants 21 Females 17 Males	University students $M_{Age} = 25$	Automated Working Memory Assessment (AWMA) Resilience Research Centre Adult Resilience Measure (RRC-ARM)	Working memory and psychological resilience in South African emerging adults.

Table 3. List of studies investigating working memory training for emotion regulation training gains.

Name of author(s)	Year	Country of study	Sample	Participant age range	Training measures and tasks	Title of study
Xui, L., Wu, J., Chang, L., & Zhou, R.	2018	China	42 Participants 26 Females 15 Males	Undergraduate and graduate students $M_{Age} = 23$ years	Attentional Network Test-short version (ANT-S) Event-related Potential (ERP) ER task; Running WM task	Working memory training improves emotion regulation ability.
Wang, X., Pan, D., Li, X., & 12th International Conference on Brain Informatics, BI 2019 12th 2019 12 13 to 2019 12 15.	2019	China	36 Participants 24 Females 12 Males	College students and graduate students $M_{Age} = 21$ years	WM-T task (Dual *n*-back) ER tasks: Watching Negative Images Condition (WNIC); Cognitive Reappraisal Condition (CRC); Attentional Dispersion Condition (ADC)	The neural mechanism of working memory training improving emotion regulation.
Long, Q., Hu, N., Li, H., Zang, Y., Yuan, J., & Chen. A.	2020	China	106 Participants 80 Females 26 Males	Undergraduate students $M_{Age} = 20$ years	Pseudotraining WM task (*n*-back; Search task) ER task	Suggestion of cognitive enhancement improves emotion regulation.
Deng, Y., Hou, L., Chen, X., & Zhou, R.	2021	China	75 Participants 75 Males	$M_{Age} = 36$ years	Running memory task Emotion Regulation questionnaire (ERQ)	Working memory training improves emotion regulation in drug abstainers: evidence from frontal alpha asymmetry.

ER: emotion regulation; WM: working memory; WM-T: working memory training.

Table 4. List of studies investigating emotional working memory training for emotion regulation training gains.

Name of author(s)	Year	Country of study	Sample	Participant age range	Training measures and tasks	Title of study
Pe, M. L., Koval, P., & Kuppens, P.	2012	Belgium	95 Participants 59 Females 36 Males	Undergraduate students $M_{Age} = 19$	Center for Epidemiologic Studies Depression Scale (CES-D) Satisfaction with Life Scale Affective *n*-back task	Executive well-being: Updating of positive stimuli in working memory is associated with subjective well-being.
Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., & Dalgleish, T.	2013	United Kingdom	34 Participants 20 Females 14 Males	$M_{Age} = 23$	eWM-T task (affective duel *n*-back) Placebo WM-T task ER task	Training the emotional brain: Improving affective control through emotional working memory training.
Xiu, L., Zhou, R., & Jiang, Y.	2016	China	40 Participants 33 Females 7 Males	Undergraduate and graduate students $M_{Age} = 23$	WM tasks (2-back task; Running WM task) ER task	Working memory training improves emotion regulation ability: Evidence from HRV.
Pan, D. N., Hoid, D., Wang, X. B., Jia, Z., & Li, X.	2020	China	98 Participants 67 Females 31 Males Anxiety traits	University students $M_{Age} = 22$	WM-T and eWM-T (dual dimension *n*-back) Spatial 2-back Depression Anxiety Stress Scales (DASS) Cognitive Emotion Regulation Questionnaire (CERQ) Explicit ER task Facial Stroop task	When expanding training from working memory to emotional working memory: not only improving explicit emotion regulation but also implicit negative control for anxious individuals.

WM: working memory; ER: emotion regulation; WM-T: working memory training; eWM-T: emotional working memory training.

Table 5. Analysis of population.

Data sources	Population																
	Contextual information																
	Age of participants		Gender		Participant characteristics				Healthy/affective states			Country of study					
	18 < 26	27 < 44	M	F	University students	Mothers	Drug abstainers	General public	Healthy	Psychological disorder	Not mentioned	United States	China	SA	United Kingdom	Belgium	Canada
1.	1		25	38	1						1	1					
2.	1		25	77	1						1	1					
3.	1		8	72	1						1	1					
4.		1	0	41		1					1	1					
5.		1	15	29				1		Anxiety							1
6.		1	28	31				1		Bipolar I disorder		1					
7.	1		17	21	1				1					1			
8.	1		15	26	1				1				1				
9.	1		12	24	1					Anxiety			1				
10.	1		26	80	1				1				1				
11.		1	75	0			1		1				1				
12.	1		36	59	1					Depression						1	
13.	1		14	20				1			1				1		
14.	1		7	33	1				1				1				
15.	1		31	67	1					Anxiety			1				
Total	**11**	**4**	**334**	**618**	**10**	**1**	**1**	**3**	**5**	**5**	**5**	**5**	**6**	**1**	**1**	**1**	**1**
Percentage (significance)	**73**	**27**	**35**	**65*** (.000)**	**67*** (.0002)**	**7**	**7**	**20**	**33**	**33**	**33**	**33**	**40* (.02)**	**7**	**7**	**7**	**7**

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

and the efficacy of the studies. The researchers observed that an array of WM and ER training tasks existed in the 15 studies that were selected for the systematic review.

Results

Population

Of the 15 studies, 11 included participants with a M_{age} of between 18 and 26 years. Of the 18–26 cohorts, 91% were university or college graduate or undergraduate students in the proximate 27–44 years of the age cohort. An undergraduate female population heavily outweighed the male population. Five studies had healthy participants; five studies included participants with anxiety, depression, and Bipolar I disorder; and five studies did not mention whether or not the participants were healthy or had any psychological disorders. The studies were conducted in six different countries, with the largest number of studies conducted in the United States and China.

Neural circuitry of working memory and emotion regulation following WM-T

The neural circuitry of WM and ER following eWM-T comprises the anterior cingulate cortex coupled with the amygdala which is responsible for improved ER (Schweizer et al., 2013). Neuronal activity in the PFC and the shared neural network between the PFC and the posterior parietal cortex is involved in ER (Deng et al., 2021). The frontoparietal brain network is important for attentional control enabling participants to disengage their attention from negative stimuli (Deng et al., 2021). Therefore, participants had access to more cognitive resources for ER as training improved their proficiency in processing information (Deng et al., 2021). Moreover, Deng et al. (2021) stated that WM-T may have decreased amygdala activity and improved the connections between the amygdala and the PFC as the PFC had more control over the amygdala (Deng et al., 2021). This resulted in ER becoming more spontaneous and less effortful (Deng et al., 2021).

Outcomes of the studies

Individuals with efficient WM are better at ER than those with weaker WM (Schmeichel et al., 2008). Moreover, individuals who are skilled at multitasking (better WM) are better at performing cognitive tasks and managing their emotional responses (ER) (Schmeichel & Demaree, 2010). Participants with higher WM spontaneously engaged in self-enhancement following negative feedback and those better at juggling multiple streams of information were more skilled at managing their ERs (Schmeichel & Demaree, 2010). Research shows that the relationship between WM and ER is not reliant on the ability to follow instructions well using WM but rather that WM is important for spontaneous ER (Schmeichel & Demaree, 2010).

Non-significant results for the relationship between mindfulness, ER, and WM were found (Dubert et al., 2016) as well as a non-significant relationship between verbal WM and ER, although visuospatial WM is associated with ER (Rutherford et al., 2016). A study by Yoon et al. (2018) found that participants with Generalised Anxiety Disorder with a weaker WM who read a sentence with negative content (i.e., events that bring about feelings of terror or helplessness), had higher levels of rumination and perseverative thinking. However, the study by Peckham et al. (2019) revealed that WM had no relation with ER in that poor WM did not intensify the effects of problematic ER. Bemath et al. (2020) state that executive functioning is implicated in both behaviour and ER, which allows individuals to respond appropriately to adversity, and found that the link between WM and resilience includes goal-directed behaviour, problem-solving, and reappraisal.

Xui et al. (2018) found that WM-T can improve ER due to the orientation function of the attention network and that WM-T could improve ER in individuals with anxiety (Wang et al., 2019). WM could play a role in attention, which is crucial for ER (Wang et al., 2019). Participants who were placed in a placebo group who expected positive results following WM-T, even though they unknowingly participated in a pseudotraining task, displayed a decrease in negative emotion and an increase in ER, regardless of training duration (Long et al., 2020). Furthermore, a study by Deng et al. (2021) showed that WM-T improved ER in drug abstainers. Subjective well-being is linked to the efficient processing of positive information using updating (Pe et al., 2013). Findings in a study by Schweizer et al. (2013) showed that eWM-T resulted in marked behavioural improvement and resulted in a clear behavioural and neural transfer to ER, therefore significantly improving ER. Xui et al. (2016) posit that WM-T could transfer to ER because improved WM updating capability is beneficial to ER. Both WM-T and eWM-T improved ER following instruction (explicit ER) while eWM-T further improved spontaneous (or implicit) ER (Pan et al., 2020).

Cognitive paradigms used in the selected studies

Fourteen different WM measures and tasks were identified across the 15 selected studies, of which four were administered more than once (see Table 6). Twelve different ER measures and tasks were identified across the 15 studies, of which two were administered more than once (see Table 7).

Quality assessment of selected studies

Question 10 of the adapted CASP tool assessed if each study discussed or analysed the reliability and validity of the instruments used for psychometric testing or tasks. It is concerning that less than half (47%) of the selected studies fulfilled this quality requirement which may have skewed results or led to biased outcomes. Fifty-three percent of the studies failed to discuss whether the training tasks had been used before, had been established by other researchers as a reliable or valid training task, or that the researchers themselves tested the reliability and validity of the training task. One study did not use an ER measure with established psychometric properties, even though its title stated that it aimed 'investigating the relationship between WM and ER in mothers' (Rutherford et al., 2016), thus limiting the construct validity of measurements in the study (Bemath et al., 2020). Ethical practices of issues related to informed consent, anonymity, and confidentiality during or after the study were not consistently found in the selected studies. Following the quality assessment, it was found that a mere 53% of the selected studies mentioned how the participants were selected or if they were representative of the target population. One study only had a sample of 18 participants (Wang et al., 2019). It was the only study with such a small sample and the small sample size was mentioned as a limitation of the study. Also, two studies offered undergraduate students partial course credit in exchange for participating in the training (Schmeichel & Demaree, 2010; Schmeichel et al., 2008), and one study offered college students compensation (Wang et al., 2019), which indirectly could have induced a response bias.

Table 6. Working memory measures and tasks administered across selected studies.

Working memory measures and tasks	Number of times administered across studies	Schedule
1. Operation Span (OSPAN)	2	Not stated.
2. Automated Operation Span (AOSPAN)	1	Not stated.
3. Wechsler Adult Intelligence Scale IV Backward Digital Span (WAIS-IV BDS)	2	Not stated
4. Running WM task	3	20- to 30-min daily over 20 days
5. Dual *n*-back	2	30 daily sessions (20–30 min) completed within 21 days/20 daily sessions (20–30 min) in 20 days.
6. Corsi Block Tapping Test (CBTT)	1	Not stated.
7. RSpan	1	Not stated.
8. Automated Working Memory Assessment (AWMA)	1	Not stated.
9. Attentional Network Test - short version (ANT-S)	1	One day before training (pretest) and the day after training (posttest)
10. *n*-back	1	20 min
11. Search Task	1	20 min daily over 7 days.
12. 2-back	1	Not stated.
13. Dual Dimension *n*-back	1	21 days completed within 4 weeks
14. Spatial 2-back	1	Not stated.

WM: working memory.

Table 7. Emotion regulation measures and tasks administered across selected studies.

Emotion regulation measures and tasks	Number of times administered across studies	Schedule
1. ER Questionnaire (ERQ)	4	Not stated.
2. ER task	3	Not stated.
3. University of Wales Institute of Science and Technology Mood Adjective Checklist (UWIST Mood Adjective Checklist)	1	Not stated.
4. Positive and Negative Affective Schedules (PANAS)	1	Not stated.
5. Difficulties in Emotion Regulation Scale (DERS)	1	Not stated.
6. Ruminative Response Scale (RSS)	1	Not stated.
7. ERP (Event-related Potential) ER task	1	Not stated.
8. Watching Negative Images Condition (WNIC)	1	Not stated.
9. Cognitive Reappraisal Condition (CRC)	1	Not stated.
10. Attentional Dispersion Condition (ADC)	1	Not stated.
11. Cognitive ER Questionnaire (CERQ)	1	Not stated.
12. Explicit ER task	1	Not stated.

ER: emotion regulation.

Discussion

The researchers found that there is a lack of available evidence that WM-T has far-transfer effects on subsequent ER. According to Lee and Xue (2018), the ER network is separate from but adjacent to WM. From a neuroscientific viewpoint, the 'adjacency' of WM-ER neural networks settles the two contradictory observations of the WM-ER dyad (Lee & Xue, 2018, p. 17). These contradictory observations refer to the performance of WM and ER as being related, and that the training of emotional WM and cognitive WM are not transferable (Lee & Xue, 2018). Far-transfer effects are very small if not absent in WM-T for ER outcomes (Pappa et al., 2020), and training one function (WM) does not necessarily mean improvement in another (ER) (Schmeichel & Demaree, 2010).

An important contradiction was found in the studies that further implicates the WM-ER dyad in WM-T. Schweizer et al. (2013) included a placebo WM-T Task (which included the updating function) low in WM demands that would not improve behaviour. However, Long et al. (2020), who based their entire study on the placebo effect of WM-T for ER outcomes, showed that the placebo group, unlike the control group, showed better regulatory effects. The study by Long et al. (2020) aimed to answer an important question regarding the contradictory findings in a growing body of studies like the one conducted by Schweizer et al. (2013), and about the contradictory views of the efficacy of WM-T by investigating placebo or expectation effects on ER. Long et al. (2020) showed that the suggestion of improving cognition significantly improved ER. This supports the apprehension about insufficient experimental control, which falls short of removing placebo effects and could be the reason why positive results were reported in WM-T studies (Long et al., 2020). Interestingly, Long et al. (2020) add that placebo effects and expectations are facilitated by the reward circuitry of the brain which triggers dopamine projection into the nigrostriatal subsystem. Dopamine is used in the gating function of WM in the striatum (Lorenc et al., 2021) and is involved in motivation (Takeuchi et al., 2015). Expectation benefits based on placebo effects activate and connect many systems in the PFC, anterior cingulate cortex, and amygdala, and these same areas of the brain are implicated in ER (Long et al., 2020). Therefore, the expectation of training gains motivates participants to invest more effort to enable achievement (Long et al., 2020). Participants activate cognitive control for positive outcomes and evaluate and enact goal-consistent behaviours (Long et al., 2020).

Emotion and motivation are mental processes that share different brain regions. However, cognition is an essential part of both emotion and motivation and plays a role in determining how much influence they have on current activities and behaviours (Crocker et al., 2013). There is evidence that cognition, emotion, and motivation are intricately entangled because these processes are executed by overlapping networks (Crocker et al., 2013). These overlapping networks include the 'PFC, cingulate, amygdala, striatum, hypothalamus, hippocampus, insula, and parietal regions' and these regions of the brain are influenced by the task or the context (Crocker et al., 2013, p. 2).

Rutherford et al. (2016) noted a considerable divergence in methodologies and assessment of WM in their study compared to previous studies. The dichotomy of self-reported ER strategies used by Rutherford et al. (2016) compared to paradigms used in previous studies instructing participants to use ER strategies in response to emotionally charged stimuli, suggested that the WM-ER dyad is influenced by the assessment context (Rutherford et al., 2016). The expectation of training gains was also mentioned as a limitation by Barkus (2020), who stated that reduced negative emotions could be brought about by participants' expectations that training will yield positive outcomes.

Limitations

The use of college students as research participants limits the ability to generalise research results to other adults and researchers need to be cautious about generalising research results obtained with this highly select group to adults in general as this threatens external validity (Gravetter & Forzano, 2010). The heterogeneity of characteristics, including gender, age, race, ethnicity, and socioeconomic status of participants can limit the ability to generalise the results to the general population (Gravetter & Forzano, 2010).

The databases that were accessed through the University of Pretoria Library did not always allow access to some of the studies that were found in reference lists. The University of Pretoria is limited in its access to all existing studies and gaining access to studies not provided by the University can become too costly for the researcher.

The language delimiter was set to English, which eliminated studies from other countries, especially from China, which appears to be at the forefront of investigation into WM-T associated with ER and the mechanisms underlying WM and ER. One such article by Peng et al. (2019) could not be included in the present study due to the full article only being available in Mandarin.

As a result of the PVO strategy being employed, there was limited consideration of methodology or data analysis in the analysis.

Conclusion

Brain reward processes used in the suggestion of training improvements could be responsible for training gains found in WM-T for ER outcomes (Long et al., 2020). The neurotransmitter, cortical dopamine, is involved in the brain reward circuitry (Long et al., 2020) and could therefore be responsible for ER outcomes following WM-T. Crocker et al. (2013) posit that cognition, emotion, and motivation are implemented by overlapping networks. WM-T could be used as an adjunct to psychological intervention, which increases mesolimbic reward regions, to further normalise frontostriatal functioning (Brooks et al., 2016).

Moreover, the disparate training tasks used in the selected studies lower the level of standardisation. This demonstrates the need for quality research in this area, as we are building a knowledge base in a relatively under-researched field, and we need to ensure that research is founded on reliable evidence.

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