

**A Systematic Exploratory Review Investigating the Relationship Between  
Working Memory and Emotion Regulation: Implications for Working  
Memory Training**

by

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submitted in fulfilment of the requirements  
for the degree

**MASTER OF ARTS IN PSYCHOLOGY**

at the

**UNIVERSITY OF PRETORIA**

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30 August 2021

## Declaration

**Student number: 19235713**

I declare that:

**A Systematic Exploratory Review Investigating the Relationship Between Working Memory and Emotion Regulation: Implications for Working Memory Training**

is my own work and all the sources I have used or quoted have been indicated and acknowledged by means of complete reference. It has not been submitted before for any other degree or examination at this or any other university.



Signature

30 August 2021

Date

## **Dedication**

This work is dedicated to everyone who had dreams and never gave up in the pursuit of achieving their goals. To everyone that has fought their own battles, faced their own demons, and fought the good fight and not only survived but became endowed with wisdom and a thirst for becoming the best versions of themselves. May your light always be a light unto others.

“Your life’s work is to find your life’s work – and then to exercise the discipline, tenacity and hard work it takes to pursue it.” – Oprah Winfrey

## Acknowledgements

I would like to thank...

- ∞ **God**, for granting me undeserving Grace during the Covid-19 pandemic, for blessing me with this wonderful opportunity, and for walking beside me throughout this journey.
  
- ∞ **Prof. D. Maree** (my supervisor at the University of Pretoria), my guiding star, who has played a pivotal part in moulding my research and for helping me make great strides from its incipient stage to its completed stage with his hard work, patience, insight, and encouragement.
  
- ∞ **Prof. Cassimjee and Ms. Mostert** (my research proposal reviewers at the University of Pretoria), for their wisdom and guidance in the endorsement of my research proposal.
  
- ∞ **Viveka Pillai** (librarian at the University of Pretoria) **and Jaqueline Harvey** (researcher at the Human Sciences Research Council), for their assistance, knowledge, and support.
  
- ∞ **My family and my fiancé**, for their motivation and faith in me.

## Ethical Clearance Certificate



### Faculty of Humanities

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6 October 2020

Dear Miss TL Venter

**Project Title:** A systematic-exploratory review investigating the relationship between working memory and emotion regulation: implications for working memory training.  
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Thank you for the application that was submitted for ethical consideration.

The Research Ethics Committee notes that this is a literature-based study and no human subjects are involved.

The application has been **approved** on 1 October 2020 with the assumption that the document(s) are in the public domain. Data collection may therefore commence, along these guidelines.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. However, should the actual research depart significantly from the proposed research, a new research proposal and application for ethical clearance will have to be submitted for approval.

We wish you success with the project.

Sincerely,

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## Ethics Statement

The researcher, whose name appears on the title page of this dissertation, has obtained, for the research described in this work, the applicable research ethics approval.

The researcher declares that she has observed the ethical standards required in terms of the University of Pretoria's Code of ethics for researchers and the Policy guidelines for responsible research.



Signature

30 August 2021

Date

## Language Editor



27 August 2021

To Whom It May Concern

**DISSERTATION BY TARRYN LEIGH VENTER – A SYSTEMATIC EXPLORATORY REVIEW  
INVESTIGATING THE RELATIONSHIP BETWEEN WORKING MEMORY AND EMOTION  
REGULATION: IMPLICATIONS FOR WORKING MEMORY TRAINING**

This letter serves to confirm that KV Consultancy (Pty) Ltd has reviewed the above mentioned dissertation by Tarryn Leigh Venter.

Should you have any questions, please contact us.

Kind regards

A handwritten signature in black ink, appearing to read 'Karusha', is positioned above the printed name.

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## Abstract

**Rationale:** Working memory and emotion regulation share a neural network and are influenced by levels of stress. Training working memory as an intervention strategy to improve emotion regulation has become popular in cognitive psychology. This systematic exploratory review investigates how the working memory-emotion regulation dyad and stress are implicated in working memory training in young adults. It argues the potential of working memory training to improve emotion regulation.

**Method:** Systematic review protocols were followed for the selection of studies using working memory training to facilitate emotion regulation functioning in young adults. An electronic database search following the PRISMA statement was conducted in which 15 studies were considered eligible. The eligible studies were assessed for quality control and analysed using the PVO (population, variables and outcomes) strategy for systematic exploratory reviews.

**Results:** From a neural perspective, the coupling of the prefrontal cortex and the anterior cingulate cortex over the amygdala, as well as dopamine release (involved in brain-reward circuitry), was implicated in working memory training to facilitate emotion regulation functioning. Stress was shown to be underrepresented and several studies were lacking ethical consideration and quality control. There is evidence of inconsistencies across studies and against the conceptual framework.

**Conclusion:** The mechanisms of reward-enhancing effects in working memory training should be explored, allowing researchers to re-evaluate the direction that the investigation in working memory and emotion regulation is taking. There is a dire need for quality control to ensure that future research is founded on quality evidence.

*Keywords:* working memory, emotion regulation, stress, working memory training, emotion working memory training, mental health disorders, prefrontal cortex, limbic system, semi-systematic reviews, systematic reviews

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## List of Abbreviations

<b>Abbreviations</b>	<b>Explanation</b>
<i>ACC</i>	Anterior Cingulate Cortex
<i>ADHD</i>	Attention Deficit Hyperactivity Disorder
<i>BD</i>	Bipolar Disorder
<i>CE</i>	Central Executive
<i>CTM</i>	Computerised Training Methods
<i>DLPFC</i>	Dorsolateral Prefrontal Cortex
<i>ER</i>	Emotion Regulation
<i>eWM-T</i>	Emotional Working Memory Training
<i>fMRI</i>	Functional Magnetic Resonance Imaging
<i>GAD</i>	Generalised Anxiety Disorder
<i>LTM</i>	Long-Term Memory
<i>MDD</i>	Major Depressive Disorder
<i>NA</i>	Noradrenaline
<i>PFC</i>	Prefrontal Cortex
<i>PTSD</i>	Posttraumatic Stress Disorder
<i>SR</i>	Self-Regulation
<i>WM</i>	Working Memory
<i>WM-T</i>	Working Memory Training

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## **Chapter 1: Introduction**

### **1.1 Introduction**

This systematic exploratory review of academic literature investigates how working memory and emotion regulation are related and the influence that stress has on the relationship. Training working memory has become popular in the field of psychology and it recently became the focus for its potential role in regulating emotions. However, there are challenges regarding the relationship between working memory and emotion regulation in working memory training studies. This study will be unpacking those challenges that researchers face. This introduction positions the importance of the present research as a systematic review investigating the relationship between working memory and emotion regulation found in working memory training studies. The purpose of this section is to briefly introduce fundamental key terms and to provide the background of the study. This is followed by the aims of the research, the research question, paradigmatic lenses, and an overview of the study.

### **1.2 Working Definitions of Key Terms**

#### ***1.2.1 Working Memory as an Executive Function***

Memory forms an essential part of our cognition and, broadly speaking, memory comprises two major subsystems namely, working memory (WM) and long-term memory (LTM). The term WM has replaced the term short-term memory (STM) (Baddeley, 1992) and is part of our cognition that assists us to not only temporarily retain information but also manipulate incoming information for the purpose of problem-solving and other mentally challenging activities in our everyday lives (Baddeley, 1992).

WM is one of the three components of executive functions (Hofmann et al., 2012). Executive functions comprise inhibitory control (possibly the most elementary component), WM, and cognitive flexibility (shifting) (Dučić et al., 2018; Hofmann et al., 2012). Executive functions are the mental processes of conscious control of thought and may be key to healthy development (Greenberg, 2006). Deficits in executive functioning result in numerous poor outcomes (including regulating emotions) and behaviour (including aggression, delinquency, depression, and attentional disorders) (Greenberg, 2006). Executive functions are central to selecting which information stays in WM as individuals are constantly exposed to new information and only some of it can be accessed (Pe et al., 2012). A key component of

concentration is WM (Barkus, 2020) which is affected by the time of day, lack of sleep, stress, illness, and age (Klingberg, 2008).

WM is involved in intellectual processes of the brain (Ahmad et al., 2016) including keeping and updating information in mind (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 updating of emotional stimuli into WM (Pe et al., 2012). Chapter 2 explains WM in more detail.

### **1.2.2 Emotion Regulation**

*Emotion regulation* (ER) is a sub-component of *self-regulation* (SR) (Schmeichel et al., 2008). The term SR involves monitoring thought, feeling, or behaviour; motivation towards effortfully matching desired standards with current states; and the ability to reduce the discrepancy between the desired standards and current states (Hofmann et al., 2012). Moreover, SR includes the ability to adapt behaviour and is a process of executive functioning (Hofmann et al., 2012; Dučić et al., 2018). Therefore, ER is essential to psychological well-being and attempts to improve experience, expression, or the duration of an emotional reaction (Schmeichel et al., 2008). It serves as an internal mechanism to avoid inappropriate aggression when cognitive resources are ‘stretched’ (Baron et al., 2009). Moreover, ER includes *reappraisal*, a cognitive approach used to reduce the emotional reaction to an unpleasant experience (Klumpp et al., 2017) which includes a re-evaluation of the situation to minimise the strength of the undesired emotion (Zhang et al., 2016). Furthermore, ER underpins personal performance across many aspects of daily life, such as family, work and sport, and can be used to operationalise psychological adaptation (Van Wijk & Martin, 2021).

### **1.2.3 Stress**

*Stress* affects our daily lives and all beings have established coping mechanisms to deal with it (Kumar et al., 2013). Stress can be defined as our reaction to mental, physical, or emotional change and may arise from any given experience or thought that elicits frustration, anger, or anxiety (Kumar et al., 2013). There are two types of stress, namely the stressor as a stimulus or long-term exposure to stressors (Kumar et al., 2013). Stress as a psychological state becomes apparent when experienced or perceived challenges to our emotional or physiological well-being exceed our coping resources and abilities (Le Roux, 2010). Ongoing

and exhaustive strains experienced during high-stress intervals may reduce WM, resulting in mental failures, and affect our emotions (Schmeichel et al., 2008; Schmeichel & Demaree, 2010; Jha et al., 2010). Experiencing these high-stress intervals with reduced WM could result in defective ER strategies being selected (Barkus, 2020). This information has led researchers to study the effects of training WM as an intervention strategy to promote the ability of individuals to regulate their emotions effectively.

#### ***1.2.4 Working Memory Training as an Intervention Strategy***

The main purpose of prevention science is to modify behaviour whereby behaviour is considered to relate to our actions, emotions, and thoughts (Greenberg, 2006). The goal of *Working Memory Training* (WM-T) is to improve WM (Fraser & Cockcroft, 2020), and improvements in WM have been established in various sampled populations following WM-T and this encourages confidence in WM-T as a means to improve cognition (Morrison & Chein, 2010; Melby-Lervåg & Hulme, 2013). Currently, published WM-T studies include a plethora of WM-T measures accessing executive functions (i.e., shifting, inhibition, and WM updating) (Pappa et al., 2020). Subsequently, this inconsistency has made it challenging to gauge whether WM-T is an effective intervention strategy (Pappa et al., 2020). Researchers have further attempted to determine if training WM (near transfer effects) could improve the functioning of ER as the untrained task (far transfer effects) (Barkus, 2020). A more detailed discussion of WM-T follows in Section 2.10.3.

### **1.3 Background of the Research**

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). Studies show that the best multitaskers have the largest WM capacity (Pollard & Courage, 2017). The modern office is also a place where individuals use their WM exhaustively with an excessive amount of information to process in WM, and a greater level of distraction associated with the modern information technology society, therefore placing higher demands on WM (Klingberg, 2008). An investigation of office workers in the USA found that they were side-tracked approximately every three minutes and that their computers generally had eight programs running simultaneously (Klingberg, 2008).

The developmental period of *emerging adulthood* (with the focus on ages 18 to 25 years), is a period of constant change as the young adult explores possibilities in partners,

careers, and ideologies (Arnett, 2000). Young adults rely on their educational status and training to establish their jobs and careers for the rest of their lives resulting in tertiary education rising from 14% to over 60% from 1940 to the mid-1990s in America and other industrialised countries (Arnett, 2000). University students are susceptible to stress caused by pressure to perform academically, becoming independent, as well as new social developments and financial burdens (Veeramachaneni et al., 2019). While only 26% of university students experience a reasonable amount of stress, roughly 73% experience psychological distress, (Saleh et al., 2017). Psychological distress could be associated with general stress that comprises all facets of life's difficulties, including psychological discomfort (Saleh et al., 2017). While each student deals with the same stress differently, neuroticism (the inclination to experience negative emotions) and low self-esteem could be stress predictors in students (Saleh et al., 2017).

Stress has been investigated for potentially reducing WM (Schmeichel et al., 2008; Schmeichel & Demaree, 2010; Woodcock et al., 2019; Douglas, 1993; Hotton et al., 2018). Studies have also shown that sleep loss and poor sleep quality, resulting from stress, impairs ER, increases pain, susceptibility to illness, and impairs attention and memory (Veeramachaneni et al., 2019). ER strategies are required during stressful periods and research has shown that WM and ER are related (Barkus, 2020; Pe et al., 2012; Peckham et al., 2019; Rutherford et al., 2016; Schmeichel et al., 2008; Schmeichel & Demaree, 2010; Wang et al., 2019). However, with compromised WM, individuals may feel unable to regulate their emotions (Pe et al., 2012; Rutherford et al., 2016; Schmeichel et al., 2008) and poor or maladaptive ER strategies could be selected (Barkus, 2020). 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). Moreover, poor WM also increases chances of getting depression (Peckham et al., 2019; Yoon et al., 2018) and the World Health Organization (WHO, 2021) has found that depression is the major cause of incapacity. A weakened WM may also lead to mood, anxiety, psychotic disorders (Barkus, 2020), and emotional disturbances (Jha et al., 2012). Although treating mental health disorders is relatively affordable, effective treatment exposure remains inadequate (WHO, 2021). The relationship between WM and ER is one reason why researchers have explored WM-T as an intervention strategy to improve ER.

In general, WM-T poses many different challenges for researchers as researchers have grappled with the limitations of WM-T for almost 20 years. There are methodological shortcomings, a lack of theory-driven, systematic approaches (von Bastian & Oberauer, 2013,

Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011), disparate cognitive paradigms, and publication bias found across WM-T studies (Pappa et al., 2020). Nonetheless, researchers maintain that WM-T could hold the key to uncovering practical methods of improving WM (Brady et al., 2019), reduce depressive symptoms (Jopling et al., 2020), and curb impulsivity (Dias, 2020). WM-T for ER outcomes is further limited in its efforts to improve ER against the dearth of available evidence that WM-T has far transfer effects on subsequent ER. This could be due to the underlying neural mechanisms underpinning WM and ER which are implicated in WM-T.

## **1.4 Justification for the Present Study**

### ***1.4.1 Justification for the Topic***

This study will allow researchers to re-evaluate the direction that the investigation in WM and ER is taking, mostly because reviews help researchers to build theory and challenge the methodological approaches by making connections from the available body of literature.

Combining prevention science and neuroscience could determine how biological processes could assist in a better understanding of preventative intervention (Greenberg, 2006). Therefore, an investigation into WM-T and the neural functioning of WM and ER, could assist researchers to better understand the use WM-T to prevent unwanted emotional reactions. Schweizer et al. (2013) offered a valuable and original study of the brain where a WM-T intervention was used in cognitive neuroscience by mapping the neural networks of the brain involved (Engen & Kanske, 2013).

However, research concerning WM, ER and WM-T for emerging adults is limited. This is concerning considering that many developmental transitions occur between the ages of 18 and 30, causing vulnerability to substance abuse and depression (Burt & Paysnick, 2012; Saleh et al., 2017). Emerging adulthood is a period of important decision-making and change, making it essential for the field of psychology to assist those at risk as they develop during this period (Burt & Paysnick, 2012).

### ***1.4.2 Justification for the Research Method***

Each research study builds upon another existing body of knowledge, enabling past research to expand with new research and, therefore, places the foundation for future directions in research (Gravetter & Forzano, 2010). For the investigation into the relationship between WM and ER, the influence of stress on WM and ER, and the implications for WM-T, the researcher chose a systematic exploratory review method as the most appropriate research

method. For these reasons, the researcher chose a semi-systematic method, with the collection of empirical studies following systematic review protocols to contribute to the overall findings of the investigation. Therefore, this research method, which included a selection of empirical studies, enabled the researcher to address the research question with more strength than a single empirical study would have (Snyder, 2019).

Moreover, systematic reviews are further justified by their need in South African research as many South African universities do not provide systematic review methods in their curriculum, therefore, conducting systematic reviews will encourage using this powerful method in South Africa (Laher & Hassem, 2020). Fortunately, their popularity has grown in the field of psychology because of their main purpose of observing research in order to express future directions in the country (Laher & Hassem, 2020). The meticulous method of conducting a systematic review has enabled researchers to progress faster which is especially relevant in South African and Africa as 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 espy future studies to demonstrate the desired effect (Snyder, 2019). Although the present study does not chiefly set out to investigate the efficacy of WM-T studies for ER outcomes, it combines the rigour and reliability of a systematic review with the conceptual framework and other reviews or meta-analysis studies regarding WM-T.

The semi-systematic review method is appropriate for topics that have been conceptualised differently and investigates how the topic has developed over time and across traditions (Snyder, 2019). The researcher traced the development of WM-T over time to track its progression to its current state. The semi-systematic review is more concerned with identifying and understanding potential implications for the topic instead of measuring efficacy (Snyder, 2019). The researcher chose to investigate implications for WM-T instead of the simple task of assessing the efficacy of the WM-T intervention. The analysis from a semi-systematic review has the potential for identifying thematical representations, theoretical standpoints, challenges within the research methodology, or the mechanisms of a theory (Snyder, 2019). The researcher did not follow a thematical analysis but instead categorised the WM-T studies according to the research aims. Therefore, the findings comprise valuable contributions such as the developmental timeline within the field, an agenda for future research, a conceptual model or categorisation, and evidence of an effect (Snyder, 2019).

## 1.5 Objectives of the Research

In the present study, the argument that the potential for WM-T as an intervention strategy to improve ER will be advanced by clarifying what the WM-ER dyad is, how stress influences this dyad, and how both are implicated in WM-T for ER outcomes. WM-T for ER outcomes could expand avenues in the field of psychology to improve the well-being of individuals, ameliorate highly stressful situations teamed with unwanted emotional responses, mitigate affective states, and treat psychological disorders. This systematic exploratory review undertakes the task of venturing into the realms of WM-T, to draw upon the theoretical and conceptual framework of the WM-ER dyad, and the influence of stress on the WM-ER dyad to enable the researcher to map the field of cognitive research (Snyder, 2019).

The practical motivations of WM-T to improve ER in empirical studies underscores the importance of investigating the WM-ER dyad to delineate the implications for WM-T and uncover caveats of WM-T to improve ER. The findings of this review will hopefully act as a catalyst for future WM-T directions for improved ER.

## 1.6 Research Aims

The systematic exploratory review seeks to identify and understand the WM-ER dyad and the influence of stress which may be implicated in WM-T. To achieve this, the systematic exploratory review is governed by the following three core aims:

Aim 1: To investigate the relationship between WM and ER whereby:

- WM is the independent variable (IV) and
- ER is the dependent variable (DV).

Aim 2: To investigate the influence of stress on the WM-ER dyad whereby:

- Stress is an additional IV in the role of moderator in the WM-ER dyad. For now, the researcher will assume that levels of stress influence the strength of the relationship between the IV (WM) and DV (ER) (Baron & Kenny, 1986).
- However, when investigating the influence of stress on WM, stress is an IV and WM is then a DV.

Aim 3: To investigate the WM-ER dyad and the influence of stress on the WM-ER dyad implicated in WM-T studies whereby:

- WM-T studies are selected through a systematic review process and analysed using a PVO strategy for systematic exploratory reviews.

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

## **1.7 Research Question**

How are the variables WM, ER and stress, as well as the relationship between them, implicated in WM-T as an intervention strategy for improving ER?

## **1.8 Paradigmatic Perspectives**

### ***1.8.1 Theoretical Framework***

In the behavioural sciences, *theories* account for the mechanisms of a specific behaviour (Gravetter & Forzano, 2010). Here, the theory encompasses ER as referring to the behaviour of emotional responses, as ER presents itself in the way that individuals conduct themselves, given the input affecting emotions. The mechanisms underlying the emotional response are due to the regulatory function of the experienced emotions. Theories assisted the researcher to organise and merge similar or contradicting observations related to emotional responses and make predictions about ER and emotional responses (Gravetter & Forzano, 2010). The function of regulating emotions is to do just that: regulate emotions as to illicit a desired and socially acceptable behaviour. However, the input (stressful situations and environments that have an effect on thinking, particularly on WM) may disrupt the regulatory function and cause the function to dysregulate, leading to unwanted behaviour. *Constructs* refer to theoretical mechanisms that assist in clarifying and predicting the behaviour (emotional response) in a theory (Gravetter & Forzano, 2010). The constructs in this study include WM-ER dyad, stress, and WM-T.

### ***1.8.2 Conceptual Framework***

The conceptual framework of the current study provides detailed explanations of the constructs in the study. The conceptual framework addresses WM and ER - how the variables function on a neural level and how they are connected or overlap – which is needed to understand their role in WM-T. The influence of stress - its neural influence on the WM-ER dyad and its involvement in various mental health disorders – is explored as a possible implication in WM-T. Lastly, WM-T as an intervention is explored, lending insight into its development and limitations. Many preventative interventions focus on supporting improved ER which implicate executive functions and the prefrontal lobes (Greenberg, 2006). Regions

of the brain, including the prefrontal cortex, and those involved in ER, are explained fully in Chapter 2 for the purpose of investigating the mechanisms underpinning WM and ER. This assisted the researcher in asking deeper questions about the neuroscientific explanations of the development or challenges of effective interventions (Greenberg, 2006). Therefore, the neural mechanisms of the WM-ER dyad and stress physiology implicated in WM-T steered the current study.

### **1.8.3 Research Paradigm**

The researcher followed a pragmatic paradigm, focusing on more practical and mixed approaches (Kivunja & Kuyini, 2017). The pragmatic approach allows for a combination of methods that could elucidate “the actual *behaviour* of participants, the *beliefs* that stand behind those behaviours, and the *consequences* that are likely to follow from different behaviours” (Kivunja & Kuyini, 2017, p. 35). This study investigates regulated emotional responses as the desired behaviour, the belief that ER regulates those emotional responses, and the consequence that emotional dysregulation leads to unwanted emotional responses and expression. This paradigm promotes a relational epistemology (the relationships between the constructs of WM, ER, stress, and WM-T which the researcher deemed as suitable for the present study) and value-laden axiology (research that is beneficial to people) (Kivunja & Kuyini, 2017). In this study, the paradigmatic perspective assisted the researcher in exploring the relationship between WM, ER, stress, and how these variables are implicated in WM-T as an intervention strategy for improving ER. The pragmatic paradigm is characterised by a rejection to marginalise a study in a positivist paradigm or in an interpretivist paradigm (Kivunja & Kuyini, 2017) which are opposed to each other. For these reasons, the researcher chose the pragmatic paradigm for the acquisition of knowledge by using all methodologies at the researcher’s disposal that assisted the ability to discover knowledge (Kivunja & Kuyini, 2017).

### **1.8.4 Methodological Paradigm**

Both qualitative and quantitative research methods are supported by the pragmatic paradigm (Kivunja & Kuyini, 2017) and qualitative data analysis provides for the many methods of investigation (including interpretative and integrative approaches) (Laher & Hassem, 2020). A mixed methods research approach was the appropriate method in assisting the researcher to gain insight into understanding how the WM-ER dyad and the influence of stress on the dyad is implicated in WM-T to improve ER.

The systematic exploratory review comprises core elements of both a systematic review and an exploratory literature review. This type of review combines insights from exploratory analysis with the powerful analytical tools of systematic reviews to provide a sound approach to analysis (Pertl & Hevey, 2012). In this way, the researcher used a research method that integrates theory from the exploratory review method and empirical evidence from selected published articles from the systematic review method. An amalgamation of the key components of both the exploratory-type review method and the systematic-type review method was used as the researcher assumed this to be the most appropriate research strategy for the topic. In that way, the current study has the ability to be flexible, to generate insights into theories for the literature study, *and* to allow for the analysis of selected published articles to be far more thorough and rigorous in its investigation. The systematic exploratory review was possibly the most appropriate research methodology for this type of research due to feasibility, practicality, and flexibility. Both types of reviews combined exploring literature and systematically reviewing published articles.

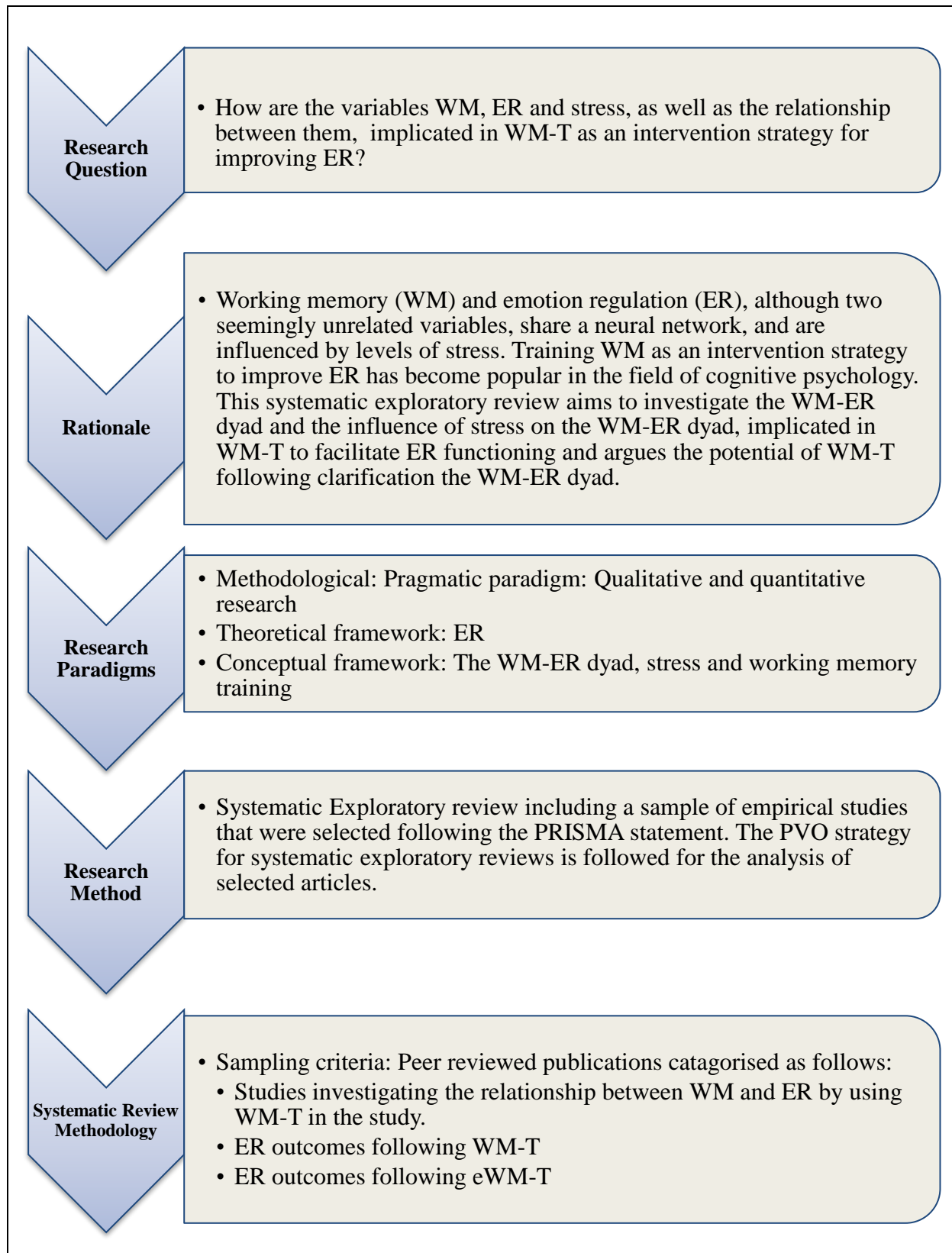
The systematic review enabled the researcher to allocate sampled studies in order to identify and formulate themes from findings. A qualitative paradigm gave detailed descriptions and accounts of the findings, which were mostly examined when conducting the research. The studies included were studies that were conducted by researchers and were peer-reviewed, with subjective methods of collecting and interpreting data, and with appropriate sources consulted for the purposes of cross-reference and corroboration (Akobeng, 2005). A critical comparison between systematic and exploratory reviews is provided in Chapter 3. The exploratory review enabled the researcher to identify research gaps and patterns in the literature review and then assess how effectively the theories fitted the data derived from selected studies in the systematic review.

## **1.9 Research Methodology**

Figure 1 outlines the systematic exploratory review methodology chosen for this study. The comprehensive discussion of the summarised points in Figure 1 will follow in Chapter 3.

**Figure 1**

*Outline of the Researcher's Methodological choices*

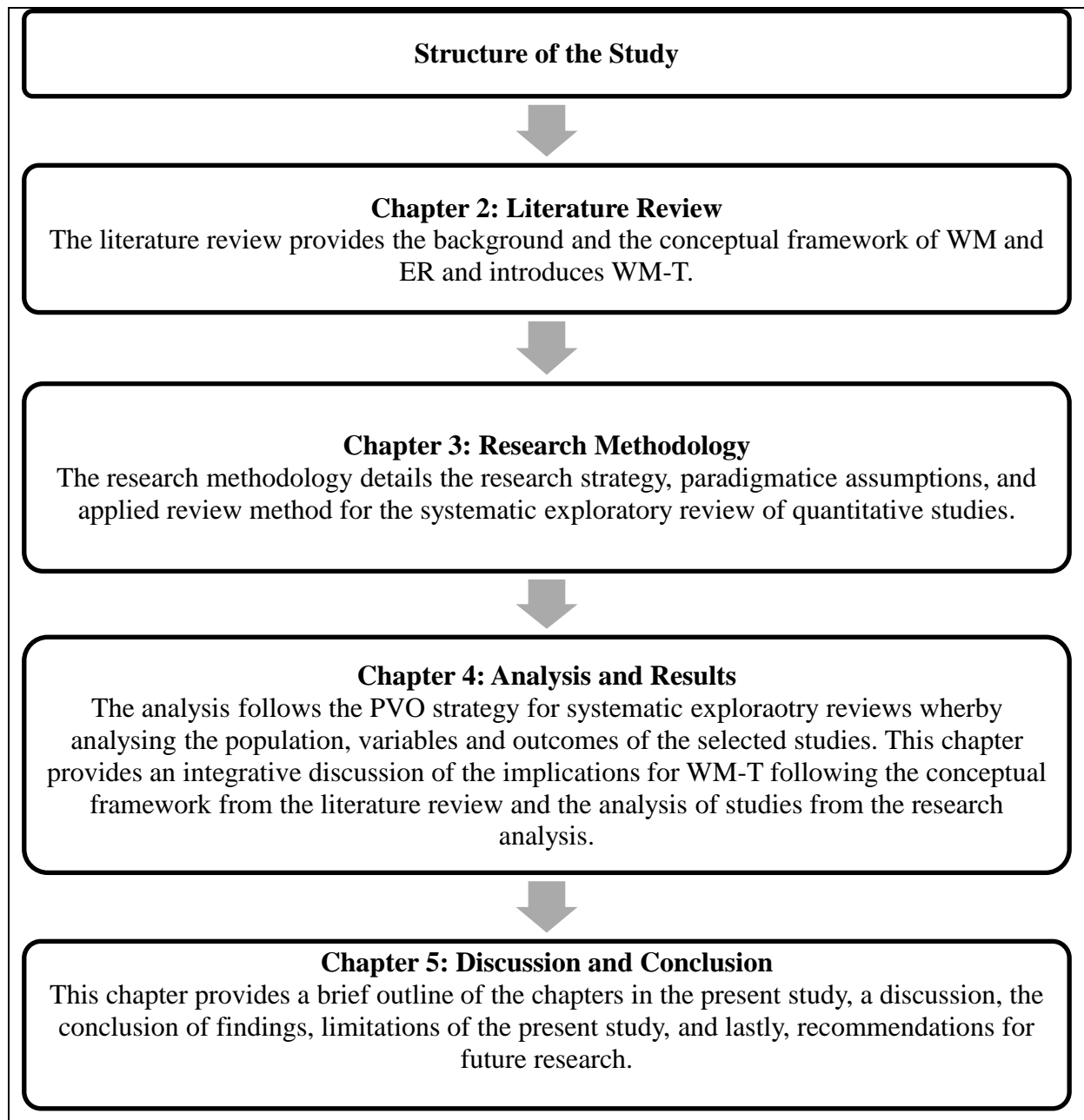


## 1.10 Structure of the Study

The structure of the study flows in a logical and coherent manner, whereby the researcher addressed the research aims and the research question. The chapters are outlined in Figure 2.

**Figure 2**

*Outline of the Chapters*



## 1.11 Chapter Outline

Stressful situations are relatable for most individuals and the possibility of having an improved WM and a better grip on emotions during stressful intervals may not only prevent job loss, divorce, anxiety, or other psychological disorders but may also assist individuals to be more resilient in various aspects of their lives and improve overall well-being. While contrasting academic literature and research exists about the efficacy of WM-T, in general, and for ER outcomes, the benefit of such an intervention is still important in psychology and cognitive neuroscience. The researcher has the intention of investigating the implications for WM-T studies so that these findings could guide the directions of future research. This could lead to a practical mental health intervention that is inexpensive, easily accessible, and tailored to individuals. Would it not be worth investigating exhaustively in a global effort, as there is recent evidence of, to improve the future of mental health?

## Chapter 2: Literature Review

### 2.1 Introduction

This chapter provides the background and conceptual framework of academic literature pertaining to WM, ER, stress, and WM-T. This literature review explores academic literature in line with the first two aims of the study. The first aim investigates the relationship between WM and ER, more specifically, the mechanisms connecting WM and ER - touching upon the neurological basis of WM and ER. The second aim investigates the influence that stress has on the WM-ER dyad. Moreover, the detrimental effects of stress on WM and ER in relation to mental health disorders. This chapter positions the conceptual framework of WM, ER, stress, and WM-T for the discussion in Chapter 5.

### 2.2 Working Memory

The following section gives a detailed explanation of WM - how it functions, what its limitations are, and its neurological basis.

#### 2.2.1 How Working Memory ‘Works’

*Short-term memory* (STM) was the archaic term for memory use that was based on remembering in the short term, as opposed to consolidated information and memories that could be retrieved from the *long-term memory* (LTM). Cognitive psychologist, George A Miller (1956), argued that the STM temporarily held a small amount of information (an average of seven items with a standard deviation [*SD*] of two) in memory in a readily-retrievable state, for typically between 10 to 15, or even a minute.

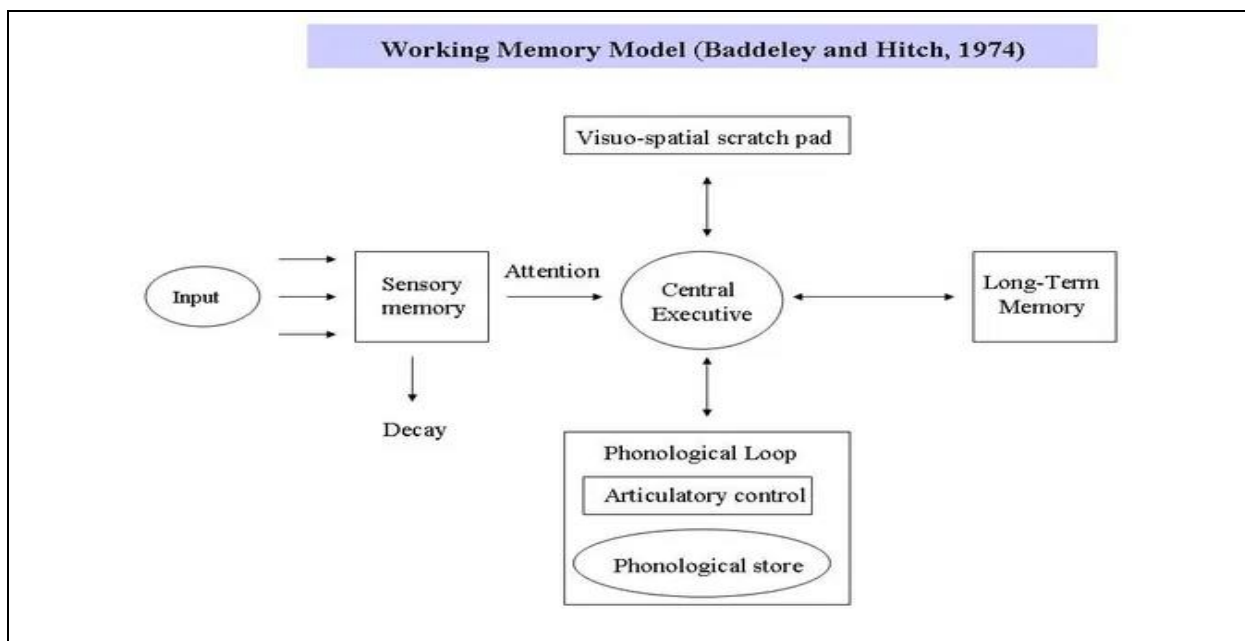
In the 1960s, neuroscientist Karl Pribram started using the term “working memory” but it is the psychologist Alan Baddeley who is most often credited with having defined it in its most common usage, in the early 1970s (Klingberg, 2008). Baddeley defined WM as “a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning” (Baddeley, 1992, p. 556). STM merely involves the retention and repetition of information, while WM denotes STM tasks that require manipulation, contain some form of distraction, or demand a degree of simultaneous performance (Baddeley, 2012).

When the idea of a single unitary store was abandoned, Baddeley and Hitch (1974) suggested that WM comprises three components. Figure 3 is a representation of the three components of WM. It comprises one component responsible for storing visual information,

termed the visuo-spatial sketch pad which is near the visual cortex; one component responsible for storing verbal information, termed the phonological loop in Broca's area which acts as an "inner voice" that uses repetition to remember); and one central component coordinating the other two termed the *central executive* (CE).

### Figure 3

*The Initial Three-Component Model of Working Memory Proposed by Baddeley and Hitch (1974)*



Note. Adapted from McLeod (2012)

<https://www.simplypsychology.org/working%20memory.html>. In the public domain.

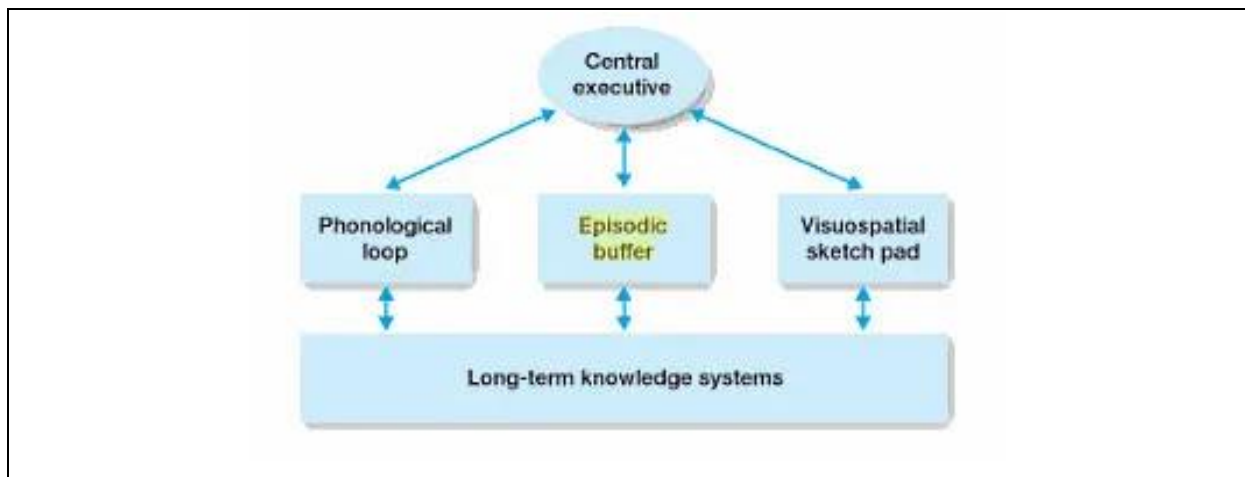
The CE controls the visuo-spatial sketch pad and the phonological loop as these two neural loops store information for a short while until the information is forgotten as new information arrives (Baddeley, 2012). Herein lies the importance of the CE: its principal role is the attentional control of action meaning that the CE is critical to WM as it coordinates attentional activities and governs responses. (Sternberg, 2009; Baddeley, 2012). The CE also monitors and coordinates the visuo-spatial sketchpad and phonological loop whilst retrieving information stored in LTM (McLeod, 2012). The CE drives the whole system and distributes information to the visuo-spatial sketchpad and phonological loop. Moreover, the CE manages

mental tasks such as calculations and solving problems (McLeod, 2012). Originally, Baddeley (1992) had established that the CE and an attention controller were part of the first component of WM and that the visuo-spatial sketch pad and the phonological loop were subsidiary slave systems of WM. Later on, Baddeley (2012) split the attentional controller from the temporary storage system as it relied on verbal and visuo-spatial systems which had limited capacities and labelled the central controller the CE. Baddeley (2012) wanted to delve deeper into the workings of the CE as its predominant role was the attentional control of action.

The revised model of WM, which has an additional component termed the *episodic buffer*, focuses on synthesising information instead of isolating the components which is useful for attempting to better understand the multifaceted nature of WM (Baddeley, 2000). The episodic buffer, which is also part of WM, is able to consolidate information from the visuo-spatial sketch pad, phonological loop, and LTM into a single episodic representation (Sternberg, 2009; Funahashi, 2017). This integration of information from separate components of WM helps us to better understand the information, assists us in problem-solving, and to re-assess past experiences with new information (Sternberg, 2009).

#### Figure 4

*The Current Version of The Multicomponent Working Memory Model (Baddeley, 2000)*



*Note.* Adapted from McLeod (2012)

<https://www.simplypsychology.org/working%20memory.html>. In the public domain.

It is important to note that there are different theoretical conceptualisations of WM, however, the multicomponent model of WM appears to offer the most empirically validated

conceptualisation (Baddeley, 2000; 2012). Other theories of WM can be found in the studies selected for the systematic review as researchers have used different models of WM as their theoretical grounding. However, this is also problematic as theories regarding the operation of WM are inconsistent: WM could either function as an extension of executive functioning or LTM, which are two parallel memory processes (Barkus, 2020).

### **2.2.2 Working Memory Capacity**

We experience incoming information and stimulus every second of our waking lives. This information needs to be filtered into what becomes temporarily remembered, manipulated in WM, incorporated and consolidated into LTM, or forgotten. Forgetting incoming information, that you received just a few seconds ago, can be frustrating. Extensive research has been done to develop the theory behind forgetting and what is responsible for making the information slip away. “There are two major explanations for forgetting, often placed in opposition: time-based decay and similarity-based interference” (Jonides et al., 2008, p. 207). In other words, information can disappear as time passes and it also can disappear because new incoming information is replacing the old information. Individual differences in WM capacity are due to broad measures of cognitive function (i.e., academic performance and fluid intelligence). However, WM limitations could also be due to other components of executive functions, such as attention (Schurgin, 2018). What individuals give attention to is what is retained in WM but when there are simultaneous pulls on attention, the brain can only retain so much. Klingberg (2008) refers to this phenomenon of biased competition as the unsophisticated process of holding attention which stimulates some neurons while ignoring others. The CE may be challenged by managing multiple tasks, briefly accessing LTM, continuing task goals, and avoiding interference during complex cognitive tasks (Fraser & Cockcroft, 2020).

Although WM is more complex in nature than the aforementioned primeval STM, it still has a limited capacity and there are large individual differences in performance (Schurgin, 2018). WM has been shown to be reduced by alcohol abuse, cannabis use, sleep deprivation, stress, and emotional arousal (Barkus, 2020). The present study will predominantly focus on stress as having an effect on WM performance.

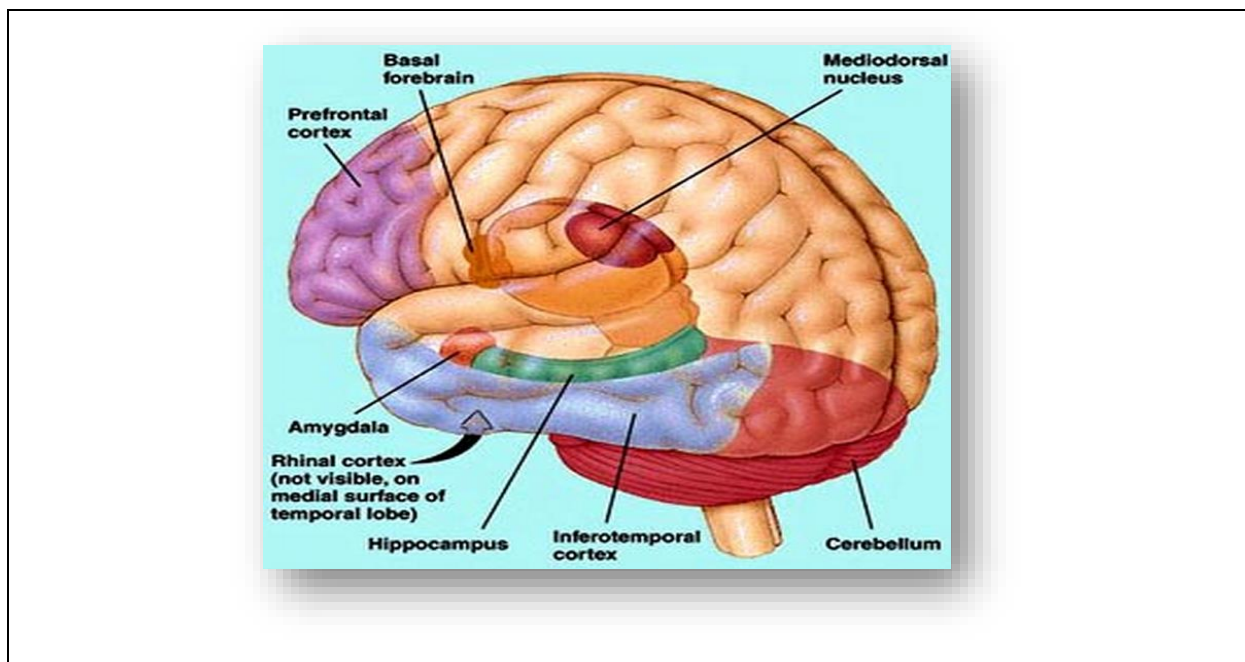
## **2.3 The Neural Basis of Working Memory**

Functional magnetic resonance imaging (fMRI) studies have enabled researchers to investigate the different parts of the brain responsible for forming memories. A network of

brain areas, known as the frontoparietal network, is consistent across most WM models (Barkus, 2020). This WM network allows for its robustness as well as its vulnerability in that reduced connections compromise its ability to function at its best (Barkus, 2020). Figure 5 is a representation of different parts of the brain involved in memory. To investigate WM, the researcher chose to discuss the PFC and hippocampus in detail.

**Figure 5**

*Parts of the Brain Involved in Memory*



*Note.* Adapted from The University of Melbourne (2016)

<http://www.kurzweilai.net/image/prefrontal-cortex2.png>. In the public domain.

### 2.3.1 Prefrontal Cortex

The prefrontal and parietal areas maintain attention that supports WM and other complex mental processes (Barkus, 2020). The CE is thought to operate in the PFC as neurophysiological studies have tried to explain how the functions of the CE activate prefrontal neurons, however, the exact neural mechanisms used for the CE in the PFC are not yet known (Funahashi, 2017). Although Baddeley did not allocate the CE to a particular brain area, shifting, updating, and inhibition are executive functions and the PFC has been

established as the area of the brain used for carrying out executive functions and forms the structural basis of executive functions (Funahashi, 2017; Dučić et al., 2018).

Different parts of the PFC are involved in different aspects of WM, and a peculiar parallelism exists between the functional organisation of the frontal lobes and the posterior cortical regions (Goldberg & Goldberg, 2009). The PFC has also been shown to be involved in stabilising ongoing activity during periods of distraction (Lorenc et al., 2021).

### **2.3.2 Hippocampus**

The hippocampus is a sea-horse-like shaped organ found in the middle of the brain and contributes to many functions including learning, memory, attention, arousal, emotions, and stress (Lathe, 2001). The hippocampus is a pivotal determinant in how we interact with and remember the world around us and modern life and technology have made people heavily reliant on visual stimuli (Pomeroy, 2019). These visual stimuli influence WM and there are signs that the hippocampus is shrinking due to our “habit-learning-memory system” (Pomeroy, 2019, p. 2). Hippocampal atrophy and deficits can affect memory and be associated with anxiety, delusion, depression, epilepsy, and schizophrenia (Lathe, 2001).

### **2.3.4 Dopamine**

Dopamine is a neurotransmitter in the brain important to WM function (Klingberg, 2008; Takeuchi et al., 2015). Animal and human studies indicate that dopaminergic release in frontostriatal circuitry is crucial for WM functioning (D’Esposito & Postle, 2014). The three major subsystems of dopaminergic neurons are the mesocortical, mesolimbic, and nigrostriatal subsystems (D’Esposito & Postle, 2014; Takeuchi et al., 2015). The first two subsystems (mesocortical and mesolimbic) originate in the midbrain and release to the frontal cortex, the anterior cingulate cortex (ACC), the nucleus accumbens, amygdala, and the hippocampus (D’Esposito & Postle, 2014). Neurons in the mesocortical system are involved in problem-solving, WM, and other complex mental functions, whereas neurons in the nigrostriatal system release to the striatum and are important for motor functioning and other complex mental functions such as filtering information to the frontal lobe, the updating function, and it is involved in motivation. (Takeuchi et al., 2015).

The striatum is conceptualised as a gate that can open and close, which controls the access of information to WM from the lateral PFC, termed ‘input gating’ (Lorenc et al., 2021, p. 236). Dopamine is thought to be significant for the gating function in WM (Morrison & Chein, 2011) as this control process may assist in prohibiting task-irrelevant information from

entering WM which interrupts current representations (Lorenc et al., 2021). This distraction-resistant control process is thought to be located in a higher portion of the intraparietal sulcus that is also sensitive to WM capacity and might be involved in storing behaviourally meaningful information in WM (Lorenc et al., 2021).

This information regarding the management of distraction and WM overload informs the discussion that follows regarding attention deficit hyperactivity disorder (ADHD) and the impact of stress on WM. Dopamine is concentrated in the frontal cortex and there is a strong release into the hippocampus (D'Esposito & Postle, 2014). More importantly, dopamine release into the dorsolateral prefrontal cortex (DLPFC) is crucial for WM (Takeuchi et al., 2015) and slight abnormalities in the dopamine system affect individuals with ADHD (Klingberg, 2008) due to the prefrontal dopamine's implication to distraction resistance (Lorenc et al., 2021).

## 2.4 Emotion Regulation

An emotion is a psychological reaction to an event “that includes physiological, experiential, and cognitive aspects, among others” (Mayer et al., 2001, pp. 233-234). Mayer et al. (2001) postulate that *emotional intelligence* is “the ability to perceive and express emotion, assimilate emotion in thought, understand and reason with emotion, and regulate emotion in the self and others” (p. 396). A general consensus exists about many emotional meanings, yet there is no uniform way of interpreting emotional states (Mayer et al., 2001). It is more useful to try to understand an individuals' reactions to a situation than the typical emotional responses of people in general (Mayer et al., 2001). The terms SR and emotional intelligence are often referred to interchangeably, however they are separate constructs.

Baron et al. (2009) defined SR as having “limited capacity to engage our willpower and control our thinking and emotions”, and refers to our capacity to regulate many aspects of our own behaviour, including aggression (p. 175). SR often requires a lot of cognitive effort and sometimes fails us due to exerted cognitive effort in other tasks, rendering little effort left to perform the important but difficult task of SR (Baron et al., 2009). Although SR, coping, mood regulation, and ER may be used interchangeably, ER has been distinguished from the others and has been clearly defined (Gross, 1998). This definition states that “ER may be regulated at five points in the emotion generative process: (a) selection of the situation, (b) modification of the situation, (c) deployment of attention, (d) change of cognitions, and (e) modulation of responses” (Gross, 1998, p. 271).

ER is related to professional and interpersonal achievements (Schweizer et al., 2013) and one way to strengthen this internal mechanism against aggression is by teaching individuals to recognise when they start to feel that their mental ability is becoming exhausted (Baron et al., 2009). It is during those periods of mental exhaustion that incite inappropriate aggression (Baron et al., 2009) and research suggests that a positive attitude towards exerting emotional control allows individuals to restrain aggression effortlessly because they think prosocial thoughts (Baron et al., 2009). In a recent study promoting psychological adaptation among navy sailors, data indicated that dispositional resilience was a small but statistically significant predictor of ER (Van Wijk & Martin, 2021). *Dispositional resilience* refers to the personal characteristic of not only having the ability to overcome hardships but to prosper despite them (Van Wijk & Martin, 2021). It is usually considered an internal trait, developed throughout life, which allows for an individual to work constructively through life's adversities, and is further considered a predictor of adaptation to stress/trauma, as well as to mental health (Van Wijk & Martin, 2021).

For this study, the terms resilience, subjective well-being, and coping are used in relation to ER. *Resiliency* is known as a protective process that uses intellectual ability to deal with stress and avoid unwanted outcomes (Greenberg, 2006). Executive functioning is involved in resilience, behaviour, and ER, assisting in the control of emotional responses in different situations (Bemath et al., 2020). There is evidence that executive functions assist young Black South Africans to be more resilient (Bemath et al. 2020). *Subjective well-being* comprises both mental and emotional components including life satisfaction (thinking about life in a positive way) and emotional balance (having more positive than negative emotions) (Pe et al., 2012). *Coping* refers to the concerted effort of an individual to control emotion, behaviour, physiology, and the environment while undergoing a stressful period and can be categorised as either engaging or disengaging from the stressor or the emotional reaction to the stressor (Evans et al., 2016).

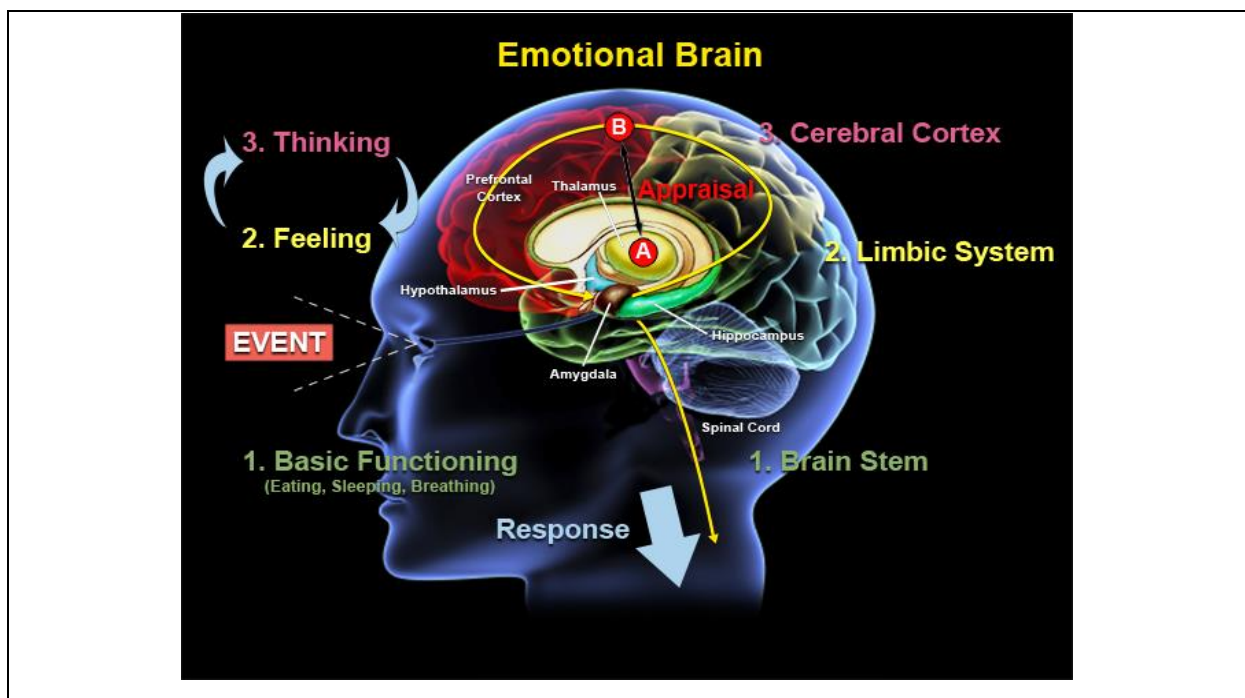
## 2.5 The Neural Basis of Emotion Regulation

Unlike WM which is predominantly located in the PFC, emotions are not found in a particular area of the brain but encompass organised brain circuits located in different areas of the brain (Fishbane, 2007). Figure 6 is a representation of the different areas of the brain involved in emotion (Alcoholicsguide, 2016). The field of social-cognitive neuroscience has concerned the orbital, dorsolateral, and limbic circuit in processing emotions, cognition, and

regulating behaviour (Greenberg, 2006). This study will discuss the amygdala, orbitofrontal cortex, and a neurotransmitter, oxytocin.

**Figure 6**

*Parts of the Brain Involved in Emotion*



*Note.* Adapted from Alcoholicsguide (2016)

<https://insidethealcoholicbrain.files.wordpress.com/2016/02/brainwordless.png?w=300&h=23>

1. In the public domain.

### 2.5.1 Amygdala

The amygdala is a subcortical structure and is essential to emotional processing and the initiation of stress responses (Eckstein et al., 2017; Krause Utz et al., 2014). When individuals feel threatened, they respond with a readiness to fight or escape as the amygdala alerts the body and hormones are released (Fishbane, 2007). This enables the muscles of the body to tense in order to carry out the chosen action (Fishbane, 2007) and sufficient control of the amygdala is essential for successful effortful ER (Zhang et al., 2016).

### **2.5.2 *The Orbitofrontal Cortex***

The orbitofrontal cortex (OFC) has been related to emotional processing and regulation (Greenberg, 2006) and carries out the brain's ER system (Fishbane, 2007). The OFC is separated from the limbic system, brain stem, and neocortex by a single synapse (Fishbane, 2007). The OFC exhibits control over the amygdala and assists individuals in the active process of becoming self-aware, flexible in their response, regulating their emotions, and being more empathetic towards others or the situation (Fishbane, 2007). However, trauma during childhood abuse or neglect can weaken the OFC's ability to carry out its function causing the amygdala to overwhelm a fully-functioning PFC (Fishbane, 2007).

LeDoux (1996) posits:

connections from the cortical areas to the amygdala are far weaker than the connections from the amygdala to the cortex. This may explain why it is so easy for emotional information to invade our conscious thoughts, but so hard for us to gain conscious control over our emotions. (p. 264)

Therefore, a damaged OFC impairs judgement, the ability to control oneself, and causes emotional control to be far more effortful (Fishbane, 2007).

### **2.5.3 *Oxytocin***

Oxytocin is a hypothalamic neuropeptide that is important for controlling social-cognitive and emotional behaviour (Eckstein et al., 2017). Studies of intranasal-oxytocin administration in healthy individuals propose that oxytocin can control emotional processing, including complex mechanisms such as ER, physical affection, and social skills (Eckstein et al., 2017).

Different parts of the brain, including the PFC, the hippocampus, and other regions of the cortex, connect with the amygdala, limbic system, and neurotransmitters that are responsible for different memory procedures and emotion. A discussion of the relationship between WM and ER follows.

## **2.6 The Working Memory-Emotion Regulation Dyad**

The relationship between WM and ER was investigated by Schmeichel et al. (2008) who revealed that people with higher WM capacity could hide negative emotions better than did those with a lower WM capacity could. "This finding shows for the first time that individual differences in WM are associated with the successful suppression of emotional

expression” (Schmeichel et al., 2008, p. 1529). The fact that WM is associated with both ER and cognition, made researchers ask if cognitive control was a unified function or if it comprised of unrelated abilities working together (Schmeichel et al., 2008). Their findings supported the unified view, as two apparently distinct abilities (storing information in WM and ER) were related, and a lower WM capacity meant a weaker ER ability (Schmeichel et al., 2008; Wang et al., 2019).

Prominent researchers and experts in the field of WM, Hofmann, Schmeichel, and Baddeley (2012), collaborated on research concerning the connection between SR and cognitive functions when they reviewed the evidence that training executive functions (including WM) held the potential for improving SR (Hofmann et al., 2012). Hofmann et al. (2012) proposed that WM, as a sub-process of executive functions, may be involved in regulating undesirable emotional expressions, desires, cravings, and supports multiple stages of ER, such as controlling aggressive behaviour. Furthermore, other researchers postulated that weakened WM is linked to emotional dysregulation (Pe et al., 2012).

Avci et al. (2013) suggest that executive functions either promote resilience if individuals are able to resist distraction in WM or impair resilience through inhibition. Unfortunately, research investigating the relationship between executive functioning and resilience in emerging adults is limited which is concerning considering that many development transitions occur between the ages of 18 and 30 (Burt & Paysnick, 2012). A recent study from South Africa investigating a possible relationship between executive functions (including WM) and resilience in young Black South Africans suggests that WM promotes resilience, in that the sociocultural environment enables behaviours involved in WM and nurtures resilience. Bemath et al. (2020) posit that this is because resilience plays a role in both behaviour and ER. Furthermore, there is also limited empirical research investigating the relationship between executive functions and coping, despite executive functions being related to successful coping (Evans et al., 2016).

Neuroimaging studies reveal activation of the prefrontal regions of the brain associated with WM whilst using ER strategies, such as reframing or reappraisal (Evans et al., 2016). Reappraisal refers to the ability of mental control processes to change the interpretation of information, once attentional focus has settled on some information, thereby changing the emotional response to the selected information (Gross, 1998). WM could play a role in attention, which is crucial for ER (Wang et al., 2019) and reappraisal is the most adaptive strategy of effortful ER (Zhang et al., 2016). Increasing evidence suggests WM appears to be fundamental in successful ER (Barkus, 2020) as there is a dispersed neural

network underpinning WM which overlaps with ER (Barkus, 2020). The next section explains the WM-ER dyad in more depth by referring to the neurological basis of WM and ER.

## **2.7 Neural underpinnings of Working Memory and Emotion Regulation**

The following section identifies and explains the intricate and complex neural mechanisms that connect WM to ER following aim one, which is pertinent in understanding how the WM-ER dyad functions for the discussion of being implicated in WM-T studies in Chapter 5.

Unconscious emotional processes can be detrimental to individuals because of the automatic reactions in the limbic system, however, conscious and thoughtful processes in the neocortical system can be beneficial to individuals (Fishbane, 2007). The limbic system contains the amygdala, which signals a ‘fight or flight’ response to incoming information which could be seen as a threat to our survival (Fishbane, 2007). Whereas, if the information travels through a more complex synaptic journey towards a higher thinking process, there would be more consideration of evaluating if the threat truly exists (Fishbane, 2007). When the amygdala is activated, emotions are intense which may cause individuals to be irrational, but when the limbic system is paired with a healthy PFC, decision-making is more guided, and emotional and relational well-being is improved (Fishbane, 2007). In the ER circuitry, the amygdala plays an essential role in emotional processing, mostly in the instinctive detection of potential threat and fear response, whereas prefrontal regions are assumed to regulate control over the amygdala, which promotes flexibility and adaptability (Eckstein et al., 2017).

Separate areas of the brain function together to form memories and emotions and are connected through neural networks (Schweizer et al., 2013). Neuroscience indicates that ER relies on the same frontoparietal neural circuitry as WM and that WM and ER are underpinned by neural substrates (Pe et al., 2012). Schweizer et al. (2013) found that ER and eWM both use the frontoparietal network, including the ACC (a region critically supporting mood regulation). The ACC plays a role in emotional processing, attention, and WM (Greenberg, 2006). Since Schweizer et al. (2013) showed that eWM-T could lead to improvements in ER, Engen and Kanske (2013) explicated that neural ER networks overlap with the frontoparietal WM network. Engen and Kanske (2013) acknowledged Schweizer et al. (2013) for having offered the first interesting study of neural networks in the brain enabling other researchers to advance evidence-based interventions to improve mental health, which was greatly valuable for cognitive neuroscience.

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., 2016). 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). Schweizer et al. (2013) stated that the ACC's coupling with the amygdala, and the strength of this coupling, determines successful ER. If there is a disturbance in connectivity from the DLPFC to the amygdala, it is indicative of inadequate prefrontal regulation (Zhang et al., 2016). The ACC is part of the cortico-limbic system (Klumpp et al., 2017) and this system is critically involved in emotional responses (Comte et al., 2014). The cortico-limbic system triggers ER and is pivotal for networks concerning cognition and emotion (Klumpp et al., 2017). The cortico-limbic system has become more pertinent to models of psychopathology (Comte et al., 2014).

Because of the extensive projections between the medial PFC and the amygdala, these regions are involved in the cortico-limbic circuitry which plays a role in ER (Eckstein et al., 2017). Furthermore, when neurotransmitters such as medial prefrontal N-acetylaspartate and glutamate decrease, emotional dysregulation is thought to increase (Kang et al., 2021). Moreover, oxytocin has been shown to increase coupling between the amygdala with medial prefrontal regions (Eckstein et al., 2017). Wolf et al. (2018) investigated the effects of single-dose selective serotonin on ER during virtual violence. The study used 38 male participants who played a violent video game, while the researchers conducted fMRI scanning on the participants, revealing that the neural circuitry of ER includes the OFC, lateral and medial PFC, the ACC, and the amygdala and that deficits in central nervous serotonin (5-HT) release impairs cognitive control of emotions (Wolf et al., 2018). Moreover, the projection of noradrenaline (NA), serotonin, and dopamine energise the actions across systems (Greenberg, 2006).

## 2.8 The Influence of Stress on Working Memory and Emotion Regulation

The researcher investigated stress as a potential moderator in the WM-ER dyad, which is in line with the second aim of the present study. A moderator is a third variable that affects the strength of the relationship between two other variables (Baron & Kenny, 1986) – namely WM and ER.

Individuals who embraced stress and thought of it as enhancing, such as those in the harrowing Navy SEALs training programme, were found to have endured the programme better than those who thought of stress as debilitating (Sanders, 2020). The researcher noted

the tendency of individuals to use stress as a motivational tool and that certain individuals thrive in stressful situations, however, the study is concerned with the effect that stress has on WM and ER, and how individuals respond during stressful periods, as well as the how stress affects our thinking and emotions on a neurological level.

According to Greenberg (2006):

central components of the stress response include the initial appraisal of the event and its emotional meaning, the ability to sufficiently regulate one's emotions and arousal to initiate problem-solving and gather more information, the fuller cognitive-affective interpretation of the event, and one's behavioural response. (p. 141)

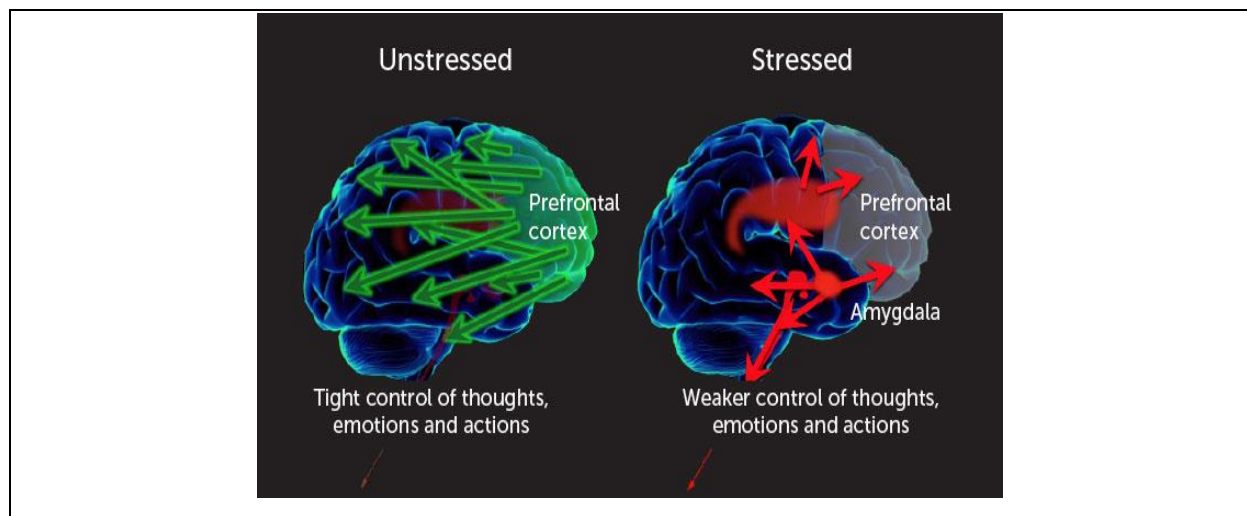
WM and cognitive flexibility have been theorised to successfully select and use coping strategies during stressful intervals (Evans et al., 2016), however, some forms of stress and anxiety may weaken WM (Schmeichel et al., 2008; Schmeichel & Demaree, 2010). Research has shown that during ongoing and exhaustive demands of high-stress periods, WM may weaken and lead to mental failures, and affect our emotions (Jha et al., 2010).

Research shows that stress impairs the activity of brain areas, including the PFC and the hippocampus, by diminishing nerve cells and disabling their networks, rendering the PFC most vulnerable (Sanders, 2020). Prefrontal networks were weakened under stressful periods due to the disturbance in neurotransmitters (Arnsten, 2009, as cited in Sanders, 2020). This finding was discovered through fMRI scans which have also shown how stress affects volunteer's thinking – they went into fight or flight autopilot-type behaviour (Sanders, 2020). To reiterate, the amygdala is responsible for the fear response and could be considered a 'hot' process, exhibiting bottom-up control, whereas the PFC could be considered a 'cool' process and exhibits top-down control of limbic areas, important for ER (Zhang et al., 2016). Figure 7 is a representation of how stress affects the PFC and leads to a weaker control of thoughts, emotions, and actions (Sanders, 2020).

The image of the unstressed brain on the left shows an alert brain with moderate amounts of neurotransmitters that enable the PFC to take control and perform high-level cognition, however, with the influence of stress, those neurotransmitters can overstimulate the brain, causing amygdala-linked brain networks involved in responding to threats to become activated (Arnsten, 2009 as cited in Sanders, 2020).

**Figure 7**

*The Effect of Stress on the Brain*



Note. Adapted from Sanders (2020) [https://www.sciencenews.org/wp-content/uploads/2020/05/060620\\_LS\\_inline-2-brains\\_desktop.jpg](https://www.sciencenews.org/wp-content/uploads/2020/05/060620_LS_inline-2-brains_desktop.jpg). In the public domain.

Stress also has a detrimental effect on our WM as it affects our attention span which can lead to mood disorders and other psychological disorders (Douglas, 1993; Hotton et al., 2018; Schmeichel et al., 2008; Schmeichel & Demaree, 2010; Woodcock et al., 2019). Worry can disrupt key cognitive functions, including WM, and worry can act as an internal distracter, thus drawing attention away from a current task and thereby lowering the capacity to control attention (Hotton et al., 2018).

Chronic stress exposure leads to helplessness and psychiatric disturbances (Viljoen & Panzer, 2007; Kumar et al., 2013; Douglas, 1993; Barkus, 2020; Evans et al., 2016). The negative effects of stress include difficulties with ER and coping, which has been associated with psychopathologies such as depression (Evans et al., 2016). Depression has been characterised by the underdevelopment of ER and deficits in executive functioning may cause depression by affecting the mental processes which are required when coping with stress (Evans et al., 2016). There are currently no investigations into the difficulties of WM detachment and dysregulated physiology of the stress response, although some theories support this association (Jopling et al., 2020). Jopling et al. (2020) conducted the first study to examine the effects of training to remove negative information on pathological symptoms and physiology in stress response in Major Depressive Disorder (MDD). The study provided new

research that removing negative information from WM through training assists in controlling the intense physiological reaction to stress (Jopling et al., 2020).

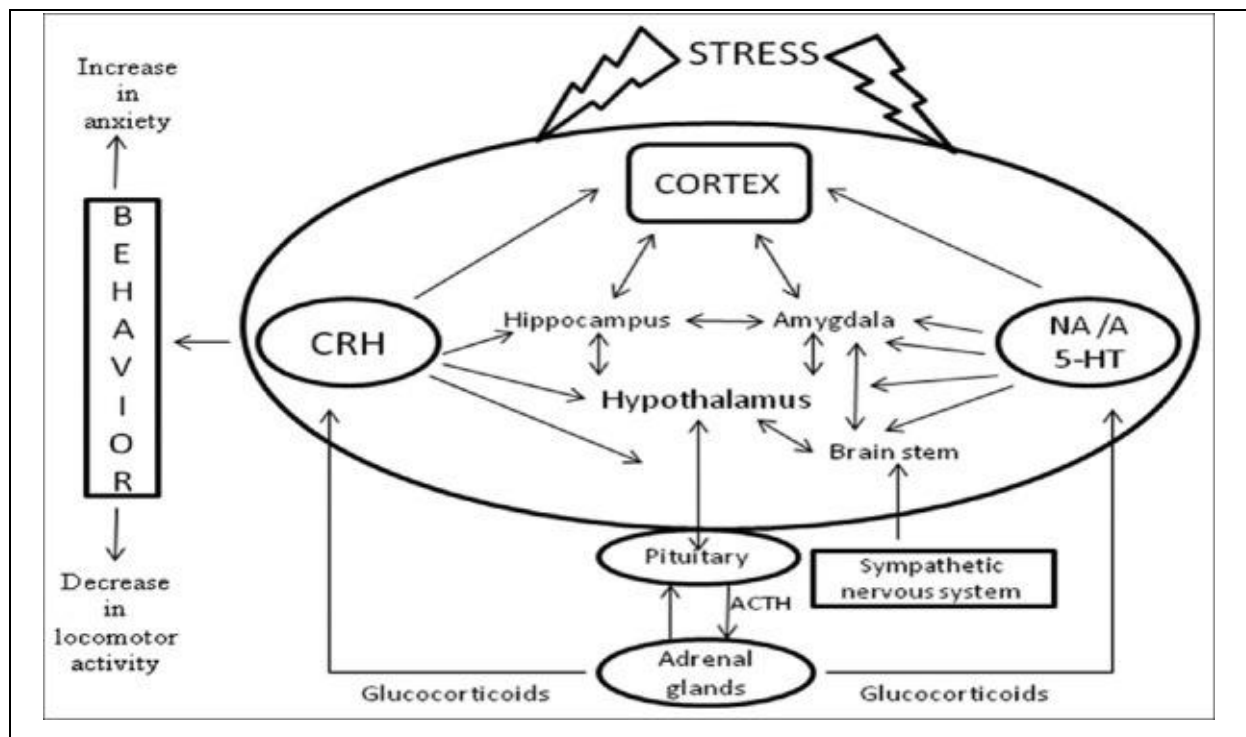
Both maladaptive ER and WM are present in many mental health disorders as ER strategies are needed during stressful intervals where cognition is challenged (Barkus, 2020). The effect of stress on physical and mental health is gaining more attention in neurological research (Kumar et al., 2013). Figure 8 is a representation of the influence that stress has on parts of the brain involved in memory, emotion, and behaviour (i.e., the cortex, hippocampus, amygdala, hypothalamus, and brain stem); the neurotransmitters that enhance the signals between those parts of the brain released by the pituitary and adrenal glands; and the sympathetic nervous system, which cumulatively effect behaviour by increasing anxiety and decreasing locomotor activity (Kumar et al., 2013).

In Figure 8, stress is seen as affecting a very complex system of interactions between parts of the brain, neurotransmitters, neuromodulators, and the nervous system. The cortex, at the top of the stress response system, includes the PFC, where WM functions are found. The cortex communicates with the hippocampus and amygdala, which are part of the limbic system and memory. They communicate with the hypothalamus which communicates with hormonal glands. Communication between parts of the brain and the pituitary gland is seen as two-directional. Within that system are neuromodulators of the central nervous system. Outside of that system, is the sympathetic nervous system which has an input into the stress response system. The outcome of the stress response system is the behaviour of the individual, which increases anxiety and decreases motor activity.

An important neuromodulator of the central nervous system is noradrenaline (NA) (Kuo et al., 2021) which can be seen inside the stress response system in Figure 8. The NA system is linked to increased brain processing of information, and focusing attention on relevant information by ignoring irrelevant information (Viljoen & Panzer, 2007). Recently, research provided evidence that NA is prominently involved in WM performance in healthy humans (Kuo et al., 2021). Studies exposing animals to stressful conditions (including severe uncontrollable stress) caused a “learned helplessness” reaction which can be compared to depression in humans and drains NA (Viljoen & Panzer, 2007, p. 138). Acute and chronic stress have effects on NA in areas such as the cerebral cortex and the subcortical areas (including the hippocampus, amygdala, thalamus, and hypothalamus) (Viljoen & Panzer, 2007). Increased NA release upon re-exposure leads to exaggerated stress responses, however, extreme stimulation may exhaust the noradrenergic supply causing the behavioural model of helplessness (Viljoen & Panzer, 2007).

**Figure 8**

*Major components of the limbic system and neurotransmitters involved in stress response*



*Note.* Adapted from Kumar et al. (2013)

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3697199/>. In the public domain.

Therefore, the NA has extensive effects on mental functioning and behaviour because of its effect on other central nervous systems, and its interaction with other neuromodulatory systems of the brainstem (Viljoen & Panzer, 2007). Chronic stress is harmful to psychiatric patients, as it affects cognition which results in diminished synaptic activity and possibly impaired neuronal networks in the limbic system (Kumar et al., 2013). This could result in damage to the cholinergic neurons (which play a vital role in cognition and perception) and cause dementia (Kumar et al., 2013).

The dorso-medial PFC is involved in the volitional ER process and instinctive control functions (including inhibiting the stress response and eliminating previously acquired reactions to fear) (Eckstein et al., 2017). Resilience has been related to using cognitive skills in dealing with stress (Greenberg, 2006) and less perceived life stress was indicated as a factor for resilience in youth ages 18 to 21 years (Burt & Paysnick, 2012). WM may contribute to our understanding of resilience as WM may be a substitute for emotional

learning, which is frequently dysregulated in stress-related psychopathology (Wingo et al., 2010). Coping flexibility and gender-neutral personality traits were found to be useful under high-stress intervals in young adults (mean age = 21) (Burt & Paysnick, 2012). Those with higher WM capacity predicted higher levels of ER that either changed the stressor or the reaction to it (Evans et al., 2016).

Stress has been thoroughly investigated over the past half-century, yet, the mechanisms of stress are still unknown due to a wide variety of cellular activities (Kumar et al., 2013). However, a more recent article by Luke et al. (2018) explains the neurobiological underpinnings of stress by explaining that the hypothalamus is a border structure between the midbrain and hindbrain that is vital for threat response through its effect on the pituitary gland after the amygdala has detected the threat (Luke et al., 2018). During stressful intervals, the pituitary gland secretes hormones and serves as the main chemical channel between the pituitary and adrenal glands (Luke et al., 2018). The adrenal cortex releases cortisol which provides a surge of energy for the body during high-stress intervals and increases cognitive functioning, if only temporarily (Luke et al., 2018).

## **2.9 The Role of Working Memory Deficits in Psychopathology**

The present study considers psychological disorders where WM deficits have been reported, as they are related to ER and stress. Both WM and *emotional memory* (long-term retrieval of memories formed during stressful periods and may rely on the amygdala and mediotemporal structures) are cognitive functions that are significant for optimal functioning in life and also for explaining neuropsychiatric disorders (Chamberlain et al., 2006).

A weakened WM has been associated with various psychopathologies such as depression, anxiety, obsessive-compulsive disorder, mood disorder, schizophrenia, and psychotic disorders (Barkus, 2020). A poor WM may also cause persistent negative thoughts (Yoon et al., 2018). Mental health conditions are increasing worldwide which causes one year of every five years lived with mental disability (WHO, 2021). Mental health conditions affect all areas of life, including performance at school or work, social interactions with friends and familial relationships, and community participation (WHO, 2021). In 2017, an estimated 792 million people had a mental health disorder which is slightly more than one-tenth (10.7%) of the global population (Ritchie & Roser, 2018). According to global statistics, the percentage of the global population with mental health and substance use disorders has increased by 46.5% since 1990 (Ritchie & Roser, 2018).

Schmeichel et al. (2008) stated that:

depression and anxiety are associated with reduced capacity for controlled processing and it remains to be seen whether individual differences in WM contribute to treatment outcomes, or whether mood and anxiety disorders undermine WM capacity and render moot any potential benefit of high WM capacity. (p. 1537)

Deficits in ER have been associated with numerous emotional disorders and researchers have endeavoured to improve ER to avert psychopathological symptoms (Xiu et al., 2018). Impoverished affective control (i.e., ER), characterizes many neuropsychiatric disorders and deficient ER is a common syndrome throughout psychiatric disorders (Schweizer et al., 2013; Long et al., 2020). ER deficiencies are considered a central feature of emotional difficulties and maladjustment and have been associated with various mental disorders, such as anxiety, depression, substance abuse, posttraumatic stress disorder (PTSD), BD, schizophrenia, obsessive-compulsive disorder, and other disorders (Xui et al., 2016; Engen & Kanske, 2013; Wolf et al., 2018; Wang et al., 2019; Lochner et al., 2021). The following disorders are discussed below: mood disorders (depression), anxiety disorders, psychotic disorders, and bipolar disorder.

### **2.9.1 Mood disorders**

*Moods* can be defined as “relatively mild, coherent affective states that last for minutes up to hours” (Lindström & Bohlin, 2011, p. 1197). Studies investigating affective states have demonstrated that negative moods are mainly linked to the weakening of WM (Lindström & Bohlin, 2011). Pe et al. (2012) stated that deficits in executive functioning are associated with decreased ER ability and appear to play a role in the initiation and preservation of mood disorders.

#### **• Depression**

More than 320 million people suffer from MDD (Jopling et al., 2020) and females have been found to be more vulnerable to depression, other internalising problems, and aggression than their male counterparts (Burt & Paysnick, 2012). WM deficits have been detected in adults suffering from depression (Evans et al., 2016) as depression is characterised by difficulty eliminating negative information from WM (Jopling et al., 2020). Studies show that greater use of ER predicted fewer depressive symptoms (Evans et al., 2016).

### **2.9.2 Anxiety Disorders**

Anxiety disorders appear in various forms including phobic, social, obsessive-compulsive disorder, or posttraumatic stress disorder (PTSD)(Ritchie & Roser, 2018).

- **Generalised Anxiety Disorder (GAD)**

An estimated 284 million people suffered from an anxiety disorder globally in 2017, making it the most widespread psychological or neurodevelopmental disorder (Ritchie & Roser, 2018). Approximately 63 percent (179 million) were female, compared to 105 million males with GAD (Ritchie & Roser, 2018). Anxiety is associated with poorer WM (Barkus, 2020) as research has found less connectivity between the ACC and the DLPFC in patients with anxiety, suggesting that less efficient connectivity in the higher-level cortical circuit is needed for effective ER (Comte, 2014). The DLPFC is associated with cognitive control and inhibition of emotional stimulation (Greenberg, 2006), however, rumination appears to be the closest symptom of anxiety linked to poor WM (Barkus, 2020).

- **Posttraumatic Stress Disorder (PTSD)**

In patients with PTSD, flashbacks occur when the amygdala is overstimulated and the PFC is briefly disabled (Fishbane, 2007). Research done by Douglas (1993) tested for differences in memory in patients with PTSD compared to physically healthy individuals. Results showed that individuals with PTSD performed more poorly in immediate recall and other memory-related retrieval tests (Douglas, 1993).

### **2.9.3 Psychotic Disorders**

- **Schizophrenia**

WM impairments in clinical disorders such as schizophrenia are characterised by a specific deficit in distraction resistance (Lorenc et al., 2021). One study suggests that stress levels may account for reduced WM in patients with schizophrenia (KrKovic et al., 2017, as cited in Barkus, 2020). Reactions to stress are also linked to poor WM in otherwise healthy high functioning schizophrenia patients (Barkus, 2020). Family members of schizophrenia patients with schizophrenia are also shown as having poor WM (Barkus, 2020).

### **2.9.4 Attention Deficit Hyperactivity Disorder (ADHD)**

Attention deficit hyperactivity disorder (ADHD) is characterized by inattention, impulsivity, and hyperactivity (American Psychiatric Association, 1994, as cited in Klingberg et al., 2002). Among the cognitive deficits in this disorder, poor WM is a critical cognitive

deficit and ADHD has been linked to impaired function of the frontal lobe (Klingberg et al., 2002). In 1997, Russell Barkley, psychologist, and leading ADHD researcher, proposed that many of the problems related to ADHD could be attributed to deficiencies in WM (Klingberg, 2008). WM impairments in clinical disorders such as ADHD are characterised by a specific deficit in distraction resistance (Lorenc et al., 2021). Children with ADHD display higher levels of positive emotion when the demand on WM is low, while those experiencing high demand levels on WM become self-critical (Barkus, 2020). ER difficulties are common among children with ADHD (Groves et al., 2020).

### **2.9.5 Bipolar Disorder**

*Bipolar disorder* (BD) is a predominant psychiatric health burden because of the emotional symptomatology of its cyclical nature of fluctuating between extreme moods of either mania or hypomania, and depression (Zhang et al., 2016). Patients with BD have difficulties with effortful ER (Zhang et al., 2016; Peckham et al., 2019) and a recent study has reported the relationship between WM and ER as being absent in patients with BD (Oh et al., 2019, as cited in Barkus, 2020). This suggests that the WM-ER dyad in clinical samples requires further attention (Barkus, 2020). Further investigation into the neural mechanism of reappraisal has been suggested by researchers as it might assist in understanding how to improve ER in patients with BD (Zhang et al., 2016). A study by Zhang et al. (2016) provided novel evidence of effective connections between the PFC and amygdala during reappraisal and proposed that the disturbance of the DLPFC and amygdala is linked to inadequate prefrontal control during reappraisal, causing inefficient ER often seen in patients with BD (Zhang et al., 2016).

In consideration of the detrimental effects of poor WM on mental health, researchers are beginning to contemplate whether WM-T can lead to improvements in ER (Barkus, 2020). The present study provides a comprehensive background of general WM-T – how it developed, what training tools and tasks have been used, and the limitations of WM-T. Thereafter a brief discussion of WM-T for ER outcomes and emotional WM-T for ER outcomes.

## **2.10 Working Memory Training**

### **2.10.1 Klingberg's Theory of Working Memory Training (2002; 2008)**

Nascent WM-T studies began with Klingberg et al. (2002) when they utilised “a new training paradigm with intensive and adaptive training of WM tasks” (p. 781) when they

conducted WM-T studies on children with ADHD. Prior to Klingberg et al. (2002), researchers had customarily treated WM as something static, an attribute immune to external influence although there are some experiments, largely from the 1970s, in which psychologists tried to improve WM in their subjects by getting them to recall numbers, but no improvement was found in WM function (Klingberg, 2008). WM was associated with different rudimentary strategies; however, no formal training methods targeting specific outcomes had yet been developed. In 2008, Klingberg published a comprehensive book concerning WM and the future of WM-T. Klingberg (2008) posited that WM is the very part of our intellectual faculties that is developable and that this is the core of the various training studies. His theory denotes that WM can indeed be improved through training, that systems are not static, and that the limits of WM can be stretched. However, Klingberg (2008) found that the WM tasks he used in his research were extremely boring, such as remembering the position of circles in a grid. One initial problem was making children, who had trouble sitting still, perform repetitive and monotonous WM exercises for weeks on end when WM was the very thing with which they had problems (Klingberg, 2008).

In repetitive skill learning, rather than learning strategies, Klingberg (2008) noted that training had to be of adequate frequency (referring to both training sessions in a day and the number of days that training had to be provided). Furthermore, tasks had to be of adequate difficulty (referring to making the task harder as soon as the trainee improves) (Klingberg, 2008). After Klingberg et al. (2002) utilised WM-T, which he thought could be of use for improving ADHD symptoms, other researchers followed suit with various WM-T studies.

### ***2.10.2 The History of Development of Working Memory Training***

A developmental timeline was drawn for WM-T to keep abreast of research and encompass changes and trends in studies. After Klingberg et al. (2002) researched WM-T in children with ADHD, researchers started conducting an array of studies on training WM to investigate its effects for a wide range of different outcomes. Interestingly, one study even investigated the WM-T effects in rats. Mohapel et al. (2006) used 4 adult rats that were trained in a water maze and the study indicated that WM-T reduced hippocampal functioning over time, which was thought to be due to increased stress.

After a growing body of literature regarding WM-T emerged, Morrison and Chein (2011) provided a review of 26 studies examining the efficacy of WM-T. They found that WM-T had improved WM successfully across a variety of sample populations, but they also explicated several limitations of WM-T (Morrison & Chein, 2011). The limitations expressed

in their study, which refer to the neural mechanisms implicated in WM-T, are expanded in Chapter 5. Much controversy between researchers became apparent concerning the value and transfer effects of WM-T. Melby-Lervåg and Hulme (2013) conducted a meta-analysis using 23 studies to clarify the issue at hand. They found that training programmes yielded consistent, temporary improvements on both verbal and nonverbal WM tasks, however, when they analysed studies that used dynamic designs with treated controls and randomisation, the efficacy of the training was shown to be frivolous. They concurred that when reviewing WM-T, it became clear that there were methodological failings in many studies (Melby-Lervåg & Hulme, 2013). Thereafter, Melby-Lervåg et al. (2016) conducted a meta-analytic review in which 87 publications were included and reported on the efficacy of WM-T on an assortment of mental functions, yet the researchers failed to study the possible benefits of WM-T for individuals who are emotionally at-risk (Hotton et al., 2018). Researchers have indicated the need to incorporate WM-T as intervention strategies for individuals with mild intellectual disabilities (Dučić et al., 2018) and that WM-T may also be beneficial for reducing worry in high-worriers (Hotton et al., 2018).

Yoon et al. (2018) posited that WM-T, which included negative distractors, could extend the effects of cognitive behavioural therapy (CBT) if individuals learn to disengage from unwanted negative stimuli, enabling lowered levels of repetitive thinking and responses. Researchers have also investigated WM-T in more practical terms, and Brady et al., (2019) make a valuable contribution to research. Brady et al. (2019) posit that persistent experience of independent information alone does not improve WM, however, relating information to associations can improve WM. In real life, individuals attempt to remember information that is not only associated with visual features but also information that has meaning and connected verbal knowledge (Brady et al., 2019) Therefore, WM-T could hold the key to uncovering practical methods of improving WM in real-life as exposure or familiarity could improve WM, even if it is practised with simple stimuli like letters and colours (Brady et al., 2019).

Luquiens et al. (2019) conducted a systematic review to investigate the efficacy of WM-T in gambling disorder, however, no efficacy data were available. Luquiens et al. (2019) postulated that studies assessing WM-T in gambling disorder were being conducted and that they were awaiting the first results and that methodological challenges had been identified. WM-T effects have been investigated on individuals diagnosed with trichotillomania (hair-pulling disorder) but Lochner et al. (2021) found WM-T to render no reduction on hair-pulling although WM showed short-term improvements. Lochner et al. (2021) stated that their

findings are an innovative contribution to improve cognitive training effects on problematic repetitive behaviours.

Keen interest has been shown in South African studies whereby WM-T has been investigated for its effects on adolescents living with HIV (Fraser & Cockcroft, 2020) and for its effects on methamphetamine drug abusers in Cape Town (Dias, 2020). A recent study by Dias (2020) which investigated the WM-T adjunct on methamphetamine drug users suggested slightly enhanced WM maintenance brain function relative to the treatment and inefficient neural functioning during the WM task on the control group. Dias (2020) found numerous limitations in the study but provided preliminary and tentative evidence of the potential that WM-T has as a treatment supplement.

### ***2.10.3 Working Memory Training Tools and Tasks***

WM-T reveals a myriad of different tools and training tasks that have been utilised in an attempt to improve WM. The following interventions are considered as WM-T tools and tasks for the purpose of this study, although many of them are not often studied as if they are WM interventions.

- **Meditation Training**

*Meditation* has been likened to concentration training and is believed to alleviate anxiety, lumbar pain, stress, headaches, and cocaine abuse, and that it affects the immune system, skin conductance, and melatonin secretion (Klingberg, 2008). Meditation training has been shown to modify both frontal brain activity and immunological response in adults (Greenberg, 2006). Meditation training has been used to improve attention function, ER, emotional experience, and regulation capacities by shifting the focus of attention to enhance emotional well-being (Xui et al., 2018; Wadlinger & Isaacowitz, 2011). WM-T studies that included worry had groups that showed significant gains when WM-T was combined with an intervention that focused on the affective arousal of thoughts, meditation, or cognitive biases and this suggests that additional interventions could address cognitive-affective reactivity (Barkus, 2020).

- **Mindfulness Training**

Jha et al. (2010) defined *mindfulness* as “a mental mode characterised by full attention to present-moment experience without judgement, elaboration, or emotional reactivity” (p. 54). Jha et al. (2010) tested mindfulness training on two military groups during high-stress predeployment intervals and found that mindfulness training may guard against functional

damages linked to high-stress environments. The study also found that although WM weakens during demanding tasks, WM can be improved through psychological training. Hofmann et al. (2012) reiterated the success of interventions such as mindfulness on WM and that WM-T may help to control impulsive drinking in alcoholics.

Dubert et al. (2016) examined the relationship between mindfulness and ER, as well as the potential mediator role of WM in this relationship; on 80 undergraduate nursing students. The study found that WM did not directly facilitate the effect of mindfulness on ER but that there was a significant effect of mindfulness on ER and WM. Therefore, ER outcomes may improve by mindfulness training that, in turn, improves WM (Dubert et al., 2016).

- Computerised Training Methods

*Computerised training methods* (CTM) were used to exploit the appeal that computer games have for children when trying to counteract the mundane nature of WM exercises for children who have ADHD, that struggle to sit still and already have poor WM (Klingberg, 2008). One problem with establishing whether CTM are useful or harmful is that it is sometimes very difficult for the scientists to control for all background factors and to ensure that the children who play a lot do not differ from the control group in other respects than just playing habits (Klingberg, 2008). Findings suggest that sports computer games do not activate the frontal lobes but arithmetical exercises, however, demand a great deal from WM and therefore activate the frontal lobes (Klingberg, 2008). WM processes are bolstered with CTM, due to attention and WM tasks being performed over numerous training sessions (Jha et al., 2010).

Younger adults performed better than older adults when using CTM on various spatial and verbal WM tasks (Brehmer et al., 2012). Cognitive neuroscience suggests that the improvement of emotional cognitive control may be achievable through CTM by placing less burden on human resources and funding and can be made more accessible to the general population through the Internet (Schweizer et al., 2013). Numerous commercial, computer-based, WM-T programmes have been developed, such as *CogMed* (<http://www.cogmed.com/>) which is accessible in 30 countries and is generally used in schools and clinics (Melby-Lervåg & Hulme, 2013). Other WM-T programmes include *Jungle Memory* (<http://www.junglememory.com/>) and *Cognifit* (<http://www.cognifit.com/>) (Melby-Lervåg & Hulme, 2013).

A computerised intervention was administered on 63 HIV+ adolescents in South Africa to investigate if WM could be improved since the virus negatively impacts WM and that adolescence is the time when WM reaches maturation (Fraser & Cockcroft, 2020). The study found significant improvements in verbal WM when CTM were conducted, however, Fraser and Cockcroft (2020) noted several limitations of the study. Studies that used standardised CTM packages across healthy participants, and those with psychological disorders (such as anxiety, PTSD, and eating disorders), reported that several studies found improvements in mood and ER (Barkus, 2020).

- Working Memory Exercises

Mental exercises need to be carried out at least eight times a week in order to be effective (Klingberg, 2008). Chess was the activity that had the most salient training effect; reading also showed to be effective, and solving crosswords had a slight but barely statistically significant positive effect (Klingberg, 2008). Dučić et al. (2018) posit that WM-T should include exercises intended to improve WM and the capacity to manipulate processed information, to improve monitoring, memorising, and recalling.

- Problem-Solving Activities

Preconceptions about memory and the outdated ways of conducting memory research have almost nothing to do with the way memory works in real life (Goldberg & Goldberg, 2009). In most real-life situations, we remember information not for the sake of remembering but as a requirement for problem-solving (Goldberg & Goldberg, 2009). It stands to reason those problem-solving abilities should improve with WM, bearing in mind the known link between these two phenomena (Klingberg, 2008).

- Leisure Time Activities

A study by Dučić et al. (2018) measuring the relation between WM, SR, intelligence, and social skills found that WM scored significantly on a subscale for leisure time. The leisure time activities included temporary, pleasant, and satisfying activities, and offered the prospect of gaining new experiences and establishing and maintaining sociable relationships (Dučić et al., 2018). Leisure time activities like recreational games, sports, and communal activities involve effortful planning and organisation as they include interaction with others by learning a variety of practical and social skills, and are characterised by freedom and fun (Dučić et al., 2018).

- Running Memory Tasks

Running memory tasks are conducted whereby a list of words or series of numbers is read out and the participant must recall the words or numbers from the list. A study found that the orientation function of attention became enhanced after 20 days following the running memory task and these results could be indicative of a link between ER and attentional control (Xiu et al. (2018). A recent study used 40 male drug abstainers, of which 20 men participated in a running memory task for 20 days, and presented results suggesting that WM-T improved the ER of drug abstainers (Deng et al., 2021).

- Mobile Phone Based-Training Applications

A study using 98 participants with high trait anxiety used a novel mobile phone-based training application to investigate the transfer effects of WM-T on ER (Pan et al., 2020). The mobile phone based-training application used WM-T tasks build into an application that was easily accessible to participants in the study (Pan et al., 2020).

#### ***2.10.4 Neural Underpinnings of Working Memory Training***

In 2011, there were only a few neuroimaging studies investigating the neural changes involved in WM-T and results generally showed that training affects a network of brain regions (Morrison & Chein, 2011). The DLPFC, posterior parietal cortex, and basal ganglia were implicated in domain-general aspects of WM (Morrison & Chein, 2011). Attempts to distinguish the neurological networks of cognitive training could assist researchers to consider the mechanisms involved (Morrison & Chein, 2011). Neuroimaging results support the idea that WM-T targets the mechanisms involved in WM and that improving WM mechanisms enables transfer (Morrison & Chein, 2011; Melby-Lervåg & Hulme, 2013). However, several limitations exist when interpreting neuroimaging findings: experimental designs and the frontoparietal network are implicated in various complex cognitive tasks, and this complexity may complicate the relationship between WM and the frontoparietal network (Melby-Lervåg & Hulme, 2013).

Takeuchi et al. (2015) investigated the effect of WM-T on mean diffusivity in young healthy adults (mean diffusivity is a neuroimaging tool for noticing microscopic differences in the dopaminergic system). The dopamine system was investigated due to its critical role in WM and for the modification of prefrontal activity used in WM (Takeuchi et al., 2015). The study found that the improvement during WM-T tasks was associated with an increase in mean diffusivity in the DLPFC and the ACC (Takeuchi et al., 2015). This suggests that WM-T changed the dopaminergic system which is normally interpreted as reduced neural components (Takeuchi et al., 2015). This means that the neural changes in areas of the brain

that are critical to WM could improve cognitive functioning brought on by WM-T (Takeuchi et al., 2015).

A systematic review conducted by Pappa et al. (2020) was the first to assess cognitive and neural outcomes following WM-T using the updating function. In the present study, the term eWM-T is used to include the updating function in WM during WM-T. The updating function is the addition of emotional stimuli into WM. The meta-analysis conducted by Pappa et al. (2020) assessed task-based functional neuroimaging information that investigated the WM-T-related effects in adults as an insufficient number of studies have investigated structural changes after WM-T (Pappa et al., 2020). Neural changes after WM-T have been identified in frontoparietal cortical regions and subcortical regions in the healthy adult population (Pappa et al., 2020). Pappa et al. (2020) report on previous studies showing decreases in grey matter in frontal and parietal cortices; increases in cortical thicknesses increases and decreases in frontal areas; and increases in connectivity between structures in the frontoparietal network after WM-T. Furthermore, Pappa et al. (2020) found functional activity changes in healthy adult studies were similar to the frontoparietal network found in the neuroimaging literature. The frontoparietal areas (including the DLPFC and cingulate gyrus among others) decreased, meaning that decreases possibly relate to neural efficiency as fewer resources are required to repeat the task after training (Pappa et al., 2020).

### ***2.10.5 Limitations of Working Memory Training***

WM-T has been investigated for its efficacy in several meta-reviews. One prominent meta-analytic review by Melby-Lervåg and Hulme (2013) clearly states the limitations of WM-T studies. The researchers deemed these limitations as the most noteworthy and consistent with the present study.

The belief that WM-T should improve cognition may bring about significant improvement after training (Melby-Lervåg & Hulme, 2013). Therefore, in expectancy of the goals of the training, participants could place more effort in the assessment after training than usual (Melby-Lervåg & Hulme, 2013). The absence of methodological standardisation across studies makes it challenging to conclude on the efficacy of WM-T across the board (Melby-Lervåg & Hulme, 2013). Discrepancies in WM-T include training and assessments intervals, assessment conditions, setting, and the choice of control groups used which can significantly affect training outcomes (Melby-Lervåg & Hulme, 2013). A methodological problem that is of concern is that several studies show transfer effects on untrained tasks (far transfer effects) while showing zero transfer effects to the trained WM (near transfer effects). Far-transfer

effects of WM-T must be caused *by* changes in WM and this issue of efficacy could be due to measures with insufficient reliability and/or Type 1 errors (Melby-Lervåg & Hulme, 2013).

## **2.11 The History of Development for Working Memory Training for Emotion**

### **Regulation Outcomes**

Studies concerning using WM-T to improve ER started to emerge after studies began investigating the relationship between WM and ER. Nascent studies tested if WM-T improved the control of emotional material (Schweizer et al., 2011). Transfer gains of improved control over affective information were found, suggesting that the findings constitute preliminary evidence that WM-T can improve problem-solving and cognitive control processes, such as decision-making, in emotionally charged environments (Schweizer et al., 2011). Yet, the study by Schweizer et al. (2011) did not have any direct reference to ER thought the study. Since transfer effects of trained EF are strongest on those with low functioning WM and have maladaptive impulses, Hofmann et al. (2012) found this to be “the most exciting evidence yet” (p. 117) for the role of executive functioning in SR. Rutherford et al. (2016) stated that WM could be involved in regulatory functioning when their study contradicted prior research by Schmeichel et al. (2008) and Schmeichel and Demaree (2010) concerning WM and ER. Rutherford et al. (2016) found that visuo-spatial WM, not verbal, WM, is related to ER. Rutherford et al. (2016) noted considerable divergence in methodologies and assessment of WM in their study compared to the two previous studies. The dichotomy of self-reported ER strategies used in 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).

Researchers found evidence that WM-T, specifically attention control, could promote ER (Xiu et al., 2018). Xui et al. (2018) explained that researchers had investigated methods of promoting ER using meditative practices, which all possibly activated the attention network (which comprises of alerting [readiness and sustained attention], orientation [selective attention], and executive control [inhibition of major distracters]).

In a transdiagnostic review of WM-T studies to improve ER, Barkus (2020) found that WM-T studies that considered ER outcomes focused on affect as the main construct. WM-T for ER outcomes was used in children, adolescents, and adults, and it was found that WM-T could improve mental efficiency, which increases the accessibility of mental resources when ER is overstretched (Barkus, 2020). Pan et al. (2020) noted that cognitive training had not

been investigated in individuals with anxiety, who had poor ER ability as these individuals could benefit from this training. Several studies reported gains in mood and ER (including anxiety, rumination, brooding, positive appraisal) (Barkus, 2020). *Rumination* is the ability to replace negative thoughts with more positive thoughts and it has been related to problems in updating information held in WM (Barkus, 2020). *Appraisal* refers to the way individuals attach meaning to information (Gross, 1998).

Training outcomes on untrained tasks following WM-T have been debated with some researchers stating far transfer effects 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). Most recently, WM-T studies have been extended to find that WM-T improves ER in individuals that abstain from drugs (Deng et al., 2021). Following nascent studies investigating the relationship between WM and ER by Schmeichel et al (2008) and Schmeichel and Demaree (2010), Pe et al (2012) postulated that emotional WM - which includes updating of emotional stimuli into WM - and ER share neural networks, and training in one construct (WM) should improve performance in the other construct (ER). A discussion of emotional working memory training (eWM-T) for improvement in ER follows.

## **2.12 Emotional Working Memory Training for Emotion Regulation Outcomes**

Pe et al. (2012) provided a novel study on whether the updating function in WM was related to subjective well-being. The study showed that selecting and updating positive information in WM improved subjective well-being and that participants experienced more positive than negative emotions in daily life (Pe et al., 2012). Not long after the relationship between WM and ER was established, WM-T for ER outcomes used updating of emotional stimuli into WM (eWM). Schweizer et al. (2013) followed up on their preliminary study from 2011 with a study that not only explored eWM-T potentially regulating emotions, but also showed a novel eWM-T protocol that improved the efficiency of the frontoparietal network. Schweizer et al. (2013) postulated that eWM-T improved ER which they considered to be a “gold standard” of affective cognitive control (p. 5301). This led researchers to further investigate WM-T with an updating function (Xui et al., 2016) and Pan et al. (2020) compared the efficacy of WM-T and eWM-T and found both trainings enhanced ER. Moreover, Pan et al. (2020) found eWM-T to be a potentially beneficial intervention for the anxiety population as training with the updating function further improved ER compared to the general WM-T.

### **2.13 Conclusion**

The literature review formed the conceptual framework for the present study which addressed the first two aims of the study. The relationship between WM and ER (aim 1) - touching upon the neurophysiological basis of WM and ER - and the influence of stress on the WM-ER dyad (aim 2) were investigated. This chapter also discussed psychological disorders concerning WM and ER. WM-T was extensively discussed, including its history of development, WM-T tools, and its limitations. The following chapter details the research methodology for conducting the systematic review of published articles for the purpose of analysing the implications for WM-T, which is in line with the third of the present study.

## **Chapter 3: Research Method**

### **3.1 Introduction**

This chapter further explores the methodological choices for the systematic exploratory review as outlined in Chapter 1. The research method, research strategy, paradigmatic assumptions, and the application of the review method are detailed in this chapter. Finally, the ethical considerations that were followed when undertaking the study are also discussed. The sample of empirical studies selected in this chapter are analysed in Chapter 4 and the results are discussed fully in Chapter 5.

### **3.2 Research Method: A Systematic Exploratory Review**

Reviews that are well-executed create a plausible framework for progressing knowledge and enabling the research to progress further (Snyder, 2019). Reviews can also offer a synopsis of search areas that are disparate and integrative (Snyder, 2019). The systematic exploratory review comprises two methods - systematic and exploratory - for empirical and theoretical perspectives. Table 1 gives a critical comparison of systematic and exploratory reviews. This information was considered when formulating the research method of the present study.

Although systematic reviews are robust, they are not always the most suitable strategy (Snyder, 2019) as there needs to be a balance between exploratory and systematic viewpoints, and preferably, any study should have a combination of both (Pertl & Hevey, 2012). Therefore, this study was systematic, but it was not a fully-fledged systematic review as such, yet it was more rigorous than a usual exploratory review. The researcher chose to conduct a semi-systematic review as it provided an overview of the topic, tracked its progress over time, used research articles, and identified knowledge gaps within the literature (Snyder, 2019).

The following section explains the research strategy and the paradigmatic assumptions that were used in the systematic exploratory review.

### **3.3 Research Strategy**

A research strategy is designed by the type of question that the research aims to answer (Gravetter & Forzano, 2010). The research question for the current study asks how the variables WM, ER and stress, as well as the relationship between them, are implicated in WM-T as an intervention strategy for improving ER?

**Table 1***A Critical Comparison Between Systematic and Exploratory Reviews*

	Systematic Reviews	Exploratory Reviews
<b>Purpose</b>	For a literature review to have sound scientific value, the systematic review ensures that the research is done thoroughly and fairly, which is the main reason for conducting a systematic review (Kitchenham, 2004). A systematic review aims to find all empirical evidence through predetermined inclusion criteria to answer a specific research question (Snyder, 2019).	The main purpose of the exploratory review is to formulate a research problem, to place emphasis on uncovering ideas and insights, and to build upon the work already done by others (Kothari, 2004).
<b>Literature Study</b>	It is an extensive and intensive research approach focusing on all literature that exists and involves a disciplined, inclusive, clear search of academic literature which can be replicated (Harris, et al., 2013; Laher & Hassem, 2020; Efron & Ravid, 2018). Identifying relationships, contradictions, methodological failings, and research gaps inform future directions for research or intervention (Siddaway et al., 2019).	An exploratory review aims to establish what theories, empirical evidence, and research methods exist in academic literature for the research topic and its broader subject area (Adams et al., 2007). The exploratory review is useful for providing ideas on common theories, methods, and data analysis conducted on the topic (Adams et al., 2007).
<b>Methods</b>	Systematic reviews are stringent in the manner in which the search is conducted and the selected studies reveal information about the research question, as well as provide results that can assist future strategies (Snyder, 2019). The selection of studies follows predefined eligibility criteria which are assessed for the risk of bias (Laher & Hassem, 2020).	The methods and design of the exploratory literature review are flexible so that many different facets of the problem are considered as and when they arise (Kothari, 2004; Pertl & Hevey, 2012).
<b>Analysis</b>	By compounding findings across studies, systematic reviews produce unbiased conclusions which are drawn from collective evidence (Siddaway et al., 2019). Systematic reviews effectively summarise the outcomes of various trials for extracting the essence of what works and what does not (Uman, 2011).	Exploratory data analysis encourages analysts to identify research gaps, patterns, formulation of hypotheses, and assess how effective the theories and hypotheses are at fitting the data (Pertl & Hevey, 2012).

The study strategy was in line with the following aims of the current study: The first aim is to identify and understand the mechanism underlying the WM–ER dyad. The field of cognition, touching upon the neural basis of WM and ER was explored. The second aim is to investigate the influence of stress on the WM-ER dyad, and the third aim is to investigate how these variables are implicated in WM-T as an intervention strategy for improving ER.

The systematic review of identifying and selecting empirical studies aimed to evaluate the research topic justifiably by following the methodology of a systematic review that is accurate, stringent, and reliable (Kitchenham, 2004). Studies regarding WM-T for ER outcomes needed to be rigorously analysed in a systematic way to avoid bias. Therefore, this study strictly adhered to the research paradigms of a systematic review. The process of conducting the systematic review was in line with the eight steps of conducting a systematic review adapted from Uman (2011) and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. A quality assessment rating was needed for each study, and the researcher used the adapted Critical Appraisal Skills Programme (CASP) tool for quantitative articles (Laher & Hassem, 2020). These measures ensured that the study was as accurate and unbiased as possible.

For the literature review, academic literature was searched without limiters in databases using key terms and Boolean functions. This made literature available for the investigations that would have normally been limited to peer-reviewed studies in the systematic review, which eliminates books and book chapters (Gravetter & Forzano, 2010). There were no limitations placed on timespan, language, samples, or study designs for the collecting of academic literature. However, for WM, the start date was set at 1956 as anything prior to that was redundant for short-term memory. The exploratory review methodology ensured that the researcher had access to literature that elicited a much broader scope of available literature pertaining to the topic, aims, and research question. Published literature, grey literature, and websites were included in the literature review as follows:

Published literature was selected from databases available to the library of the University of Pretoria which included articles from journals, ebooks, and chapters from encyclopaedias. Printed books were also used as secondary sources. There were no limiters placed on collecting academic literature yet the researcher ensured that the literature was in line with the research topic. Literature pertaining to (a) interference resolution as the input into WM, or (b) intelligence, or (c) academic performance as a variable in relation to WM was not included in the literature review. Grey literature included Google Scholar and WorldCat which were utilised to collect literature not available in the University of Pretoria's

library and various websites and articles were used for collecting images used in the literature survey.

The present study was designed to ensure that the literature review and the systematic review covered the research topic extensively and the research strategy drives the process of the research question is answered as clearly as possible. The paradigmatic assumptions for the systematic review are outlined and discussed in the following section, followed by the application of the review method of the current study to fit these criteria.

### **3.4 Paradigmatic Assumptions**

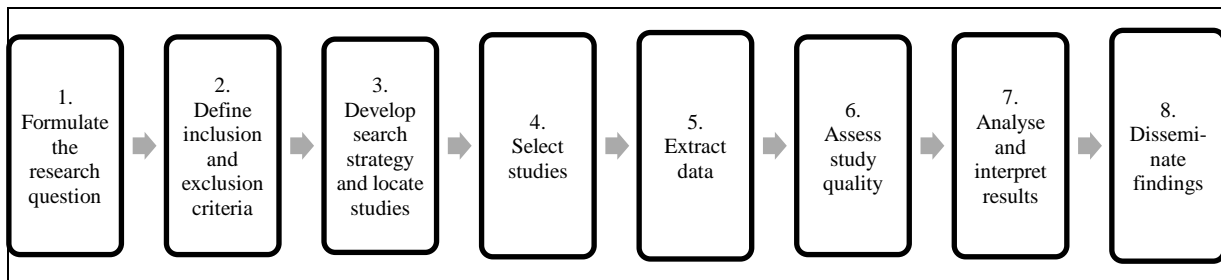
The following paradigmatic assumptions were observed in the systematic exploratory review. It was important for the researcher to provide an outline of the topic and research problem, and the development of the topic as literature reviews are used to determine the current standing of a particular topic and to identify where the gaps in the research exist (Snyder, 2019). By conducting the systematic review of published articles as part of the systematic exploratory review, which allows for clear and orderly methods for finding and selecting articles, bias can be reduced, therefore providing trustworthy findings from which conclusions can be made (Snyder, 2019). For conducting the systematic review of published articles, the present study follows the eight stages of a systemic review adopted from Uman (2011). The criteria for each stage of the systematic review are outlined below in Figure 9 and discussed thereafter. The decision to utilise this systematic review criterion ensured that the selection of published articles was done thoroughly followed ethically sound practice procedures.

#### ***3.4.1 Formulate the Research Question***

A systematic review should be able to answer an important question or identify important areas in the literature that have not been sufficiently reported on (Harris et al., 2013). A suitable research question should be innovative and narrowly defined (Harris et al., 2013) and prior research on the topic needs to be conducted before developing the research question (Laher & Hassem, 2020). The study should have a specific research question from the beginning to ensure that the most appropriate paradigm and methodology are selected to solve the particular research problem (Snyder, 2019).

**Figure 9**

*The 8 Stages of a Systematic Review (Uman, 2011)*



### **3.4.2 Define Inclusion and Exclusion Criteria**

Predetermined inclusion and exclusion criteria ensure that evidence from the selected studies is correct and unbiased (Efron & Ravid, 2018). Criteria such as ages of participants, trial conditions, trial outcomes, type(s) of interventions used, and the inclusion and types of control groups need to be decided on a priori (Uman, 2011). For the purpose of assessing the efficacy of interventions and reducing the impact of publication bias, grey literature may be used (Adams et al., 2016; Silva et al., 2017). Grey literature refers to information that is informally published and not governed by publication bodies (Adams et al., 2016).

### **3.4.3 Develop the Search Strategy and Location of Studies**

Search strategies include searching various applicable electronic databases, checking reference lists, conducting hand searches, and communicating with experts and knowledgeable researchers within the discipline (Uman, 2011). A systematic review requires the researcher(s) to find an optimal number of key studies by using an impartial search strategy (Kitchenham, 2004; Harris et al., 2013). Kitchenham (2004) states that systematic reviews must be conducted with a predefined search strategy to fulfil the extensiveness of the search. Setting a limiter in the advanced search option to peer-reviewed journals eliminated books and book chapters, and dissertation abstracts that are produced by new Ph.D.'s every year (Gravetter & Forzano, 2010). Limiting the search to peer-reviewed journals adds another level of screening to ensure that the articles identified are legitimate and worthwhile contributions (Gravetter & Forzano, 2010).

#### **3.4.4 Select the Studies**

A reporting system such as PRISMA may be utilised (Laher & Hassem, 2020) for selecting eligible studies. PRISMA is an international statement for conducting and reporting systematic reviews and meta-analyses (Melby-Lervåg & Hulme, 2013). The PRISMA statement is available at [www.prisma-statement.org](http://www.prisma-statement.org).

#### **3.4.5 Extract Data**

The research question guides the extraction of data (Laher & Hassem, 2020) and once all exclusion criteria have been adhered to, the eligible studies are identified for analysis, and the parameters of the studies are grouped on data collection forms (Harris et al., 2013).

#### **3.4.6 Assess Study Quality**

Each eligible study must be assessed for quality in order to gauge its bearing, research design, research methodology (including how the participants were selected, ethical considerations, and research procedures that were followed), analysis, as well as the findings (Uman, 2011). Researchers must exhaustively attempt to find and report studies that either do not fit their preferred research theory or support it (Kitchenham, 2004). Kitchenham (2004) provides reasons why it is generally considered important to assess the quality of primary studies:

To provide still more detailed inclusion/exclusion criteria. To investigate whether quality differences provide an explanation for differences in study results. As a means of weighting the importance of individual studies when results are being synthesised. To guide the interpretation of findings and determine the strength of inferences. To guide recommendations for further research. (p. 10)

Each selected full-text article needs to be assessed for its quality in order to reduce bias and this is done by using a quality assessment tool (Laher & Hassem, 2020).

#### **3.4.7 Analyse and Interpret Results**

The final and most important part of the research study includes drawing conclusions from the findings and making recommendations (such as reporting on the efficacy of certain interventions which are applicable for whom, and under what circumstances), and identifying research directions for further research (Uman, 2011, Harris et al., 2013).

### ***3.4.8 Disseminate Findings***

The last step is the distribution of the findings through numerous publications, academic journals, and books (Uman, 2011).

## **3.5 Applied Review Method: Systematic Review of Sampled Publications**

The systematic review of sampled publications complied with the eight stages of a systematic review adopted from Uman (2011) that was outlined in Section 3.4. The following section details the application of the present study to undertake the systematic review of sampled publications. The systematic review was performed following the PRISMA statement. The focused research question used the PVO strategy (Silva et al., 2017) for systematic exploratory reviews, which was applied in the inclusion and exclusion criteria of studies. The selected studies aim to effectively summarise the outcomes of various trials for extracting the essence of what works and what does not (Uman, 2011).

The application of the review methodology following the eight stages of a systematic review adopted from Uman (2011) is detailed below.

### ***3.5.1 The Research Question***

How are the variables WM, ER and stress, as well as the relationship between them, implicated in WM-T as an intervention strategy for improving ER?

### ***3.5.2 Inclusion and Exclusion Criteria***

The researcher selected studies based on three components following the PVO strategy for systematic exploratory reviews (Silva et al., 2017) which include:

P: population

V: variables

O: outcome

The three components of the PVO strategy which are applied to the present review are stated in Table 2, followed by the inclusion and exclusion criteria that were utilised in the selection of published articles.

The search criteria for the selection of published articles utilised the following inclusion criteria:

**Table 2***Application of the PVO strategy for Sampled Data Sources*

<b>P</b> (Population)	<b>V</b> (Variables)	<b>O</b> (Outcomes)
<ul style="list-style-type: none"> <li>• Adults between the ages of 18 and 60 years</li> <li>• Males and females</li> <li>• All races and ethnic groups</li> <li>• Healthy and affective populations</li> </ul>	<ul style="list-style-type: none"> <li>• The WM-ER dyad</li> <li>• The influence of stress on the WM-ER dyad</li> </ul>	<ul style="list-style-type: none"> <li>• Significant results in the WM-ER dyad following WM-T</li> <li>• Significant ER outcomes following WM-T and eWM-T</li> </ul>

- Publication Type

Published and peer-reviewed articles were selected from databases available to the library of the University of Pretoria. These included articles from journals that have all been evaluated and approved by experts in the field before they are accepted for publication (Gravetter & Forzano, 2010).

- The Methodology to Empirical Study

This focused the search on research reports and eliminated essays, discussions, and general review articles. Systematic review and meta-analysis studies were excluded from the selected of eligible studies as single empirical studies were preferred.

- Timespan

The search initially included all years, but due to the cyclical nature of refining inclusion and exclusion criteria (Laher & Hassem, 2020) the inclusion dates became limited to certain years for WM-T - anything prior to the year 2002 was not included due to WM-T studies only taking ground from then onwards. All start dates were extended to the current date to include anything new, as upcoming studies regarding WM-T for ER outcomes are advancing.

- Language

The studies are limited to the English language.

- Samples

The minimum age for samples was 18 years but is not entirely limited to adults between the ages of 18 to 30 years. This target age group was preferred as young adults have been shown to be the most prominent media multitaskers in the learning environment (Pollard

& Courage, 2017), coupled with the developmental changes of emerging adulthood (Arnett, 2000). However, there were not enough studies when the age limiter was set to 18 to 30 years, therefore the maximum age was extended to 60 years. Both genders were included in studies as well as participants of all races and ethnic groups, from any country of the given study. Patient samples (medical or psychiatric), as well as healthy samples, were included.

- Search Terms for the Database Search Consisted of

Working memory, working memory training, emotional working memory training, emotion regulation, and stress. Search terms were combined with Boolean functions such as AND and OR.

- Study Designs

Articles are all-inclusive of different study designs used in trials.

The search criteria for the selection of published articles utilised the following exclusion criteria:

- The selection of studies did not focus on (a) interference resolution as the input into WM, or (b) intelligence, or (c) academic performance as a variable in relation to WM.
- The samples did not include children (<18 years) or aging adults (>60 years).

Excluded studies, with the reasons for exclusion, are included in the data extraction form (Appendix C).

### ***3.5.3 The Search Strategy and Location of Studies***

The database search of online literature was used to select publications and scholarly articles and was conducted from January to August 2021. To do so, the researcher accessed the University of Pretoria's library of online resources and conducted the systematic search through consultation with the library assistant at the University of Pretoria as the latter is specialised in conducting systematic searches.

- Databases

Electronic databases available through the University of Pretoria's Library and Google Scholar were searched by the researcher. WorldCat and Google Scholar were used to source grey literature and were set as limited to the University of Pretoria Library. There were hand-searched articles and sources were also more credible if the research studies were done by well-known researchers in the field and were inclusive of South African-based studies. Table 3 summarises the databases utilised in conducting the database search of published articles.

**Table 3***Database Selection and Reason for Selection*

Search Engine	Reason for Selection
ProQuest Central	It is the largest single periodical resource available, bringing together complete databases across all major subjects (Swansea University, 2021).
ScienceDirect	Full-text scientific database offering journal articles and book chapters from nearly 2 500 journals and more than 30 000 books (City University of New York, n.d.). It provides access to a large bibliographic database of scientific and medical publications of the Dutch publisher Elsevier (Baishideng Publishing Group, 2021).
Sage	Sage is the world's largest independent academic publisher and is committed to global dissemination of research (Sage Publishing, 2021).
PsycInfo	The American Psychological Association's (APA) renowned resource is the largest resource devoted to peer-reviewed literature in behavioural science and mental health. It contains over 3 million records and summaries, all in the field of psychology (David L. Rice Library, 2021).
PsycArticles	PsycArticles, from the American Psychological Association (APA), is a definitive source of full-text, peer-reviewed scholarly and scientific articles on current issues in psychology. It contains more than 153 000 articles from nearly 80 journals published by the APA (David L. Rice University, 2021). PsycArticles database covers general psychology and specialized, basic, applied, clinical, and theoretical research in psychology (Texas Wesleyan University, 2021).
Academic Search Complete	It is a multidisciplinary database giving access to the electronic version of articles from more than 8 500 scientific journals, of which 7 300 are peer-reviewed (University of Pretoria Library, 2021).
PubMed Central	PubMed Central is a free full-text archive of biomedical and life sciences journal literature at the U.S National Institutes of Health's National Library of Medicine (David L. Rice Library, 2021).
SpringerLink	Publisher of professional and scholarly books, journals, and encyclopaedias in nursing, gerontology, psychology, and social services (University of Pretoria Library, n.d.).
Wiley Online Library	Multidisciplinary collection of online resources covering life, health, and physical sciences, social science, and humanities (The University of Notre Dame Australia, 2021).
Taylor & Francis Journals	Taylor & Francis Journals span all areas of Humanities, Social Sciences, Science, and Technology (Université de Fribourg, n.d.).
WorldCat	Provides access to a catalogue of books, articles, and other materials in libraries worldwide. The search was set to University of Pretoria libraries from the Google Scholar search (University of Pretoria Library, n.d.).
Google Scholar	Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. (University of Pretoria Library, n.d.). The search was set to University of Pretoria libraries

- Websites

The Human Sciences Research Council (HSRC) ([www.hsrc.ac.za](http://www.hsrc.ac.za)) which is South Africa's statutory research agency, was consulted for research projects relating to WM, ER, or WM-T, however, search results were null.

### 3.5.4 Selection of Studies

Folders for each database were created and articles were systematically saved by utilising referencing software. The researcher used EndNote as the chosen referencing software, due to its availability to the University of Pretoria and benchmark status. The researcher kept track of studies reviewed, their citations, and the reasons to include/exclude them in a data extraction form (refer to Appendix C). To document information obtained, titles, abstracts, and full-text articles were assessed for eligibility by applying inclusion and exclusion criteria to ensure that all the included articles were relevant to the topic (refer to Appendix B for details of the search). The researcher's supervisor assisted with the selection strategy process by reviewing the studies for selection after screening, thereby reducing bias.

The systematic review followed the PRISMA statement and an overview of the steps that the researcher followed in accordance with the PRISMA flow diagram is illustrated in Figure 10. This technique was followed because it was found to be the most comprehensive in conducting and identifying relevant studies for this research.

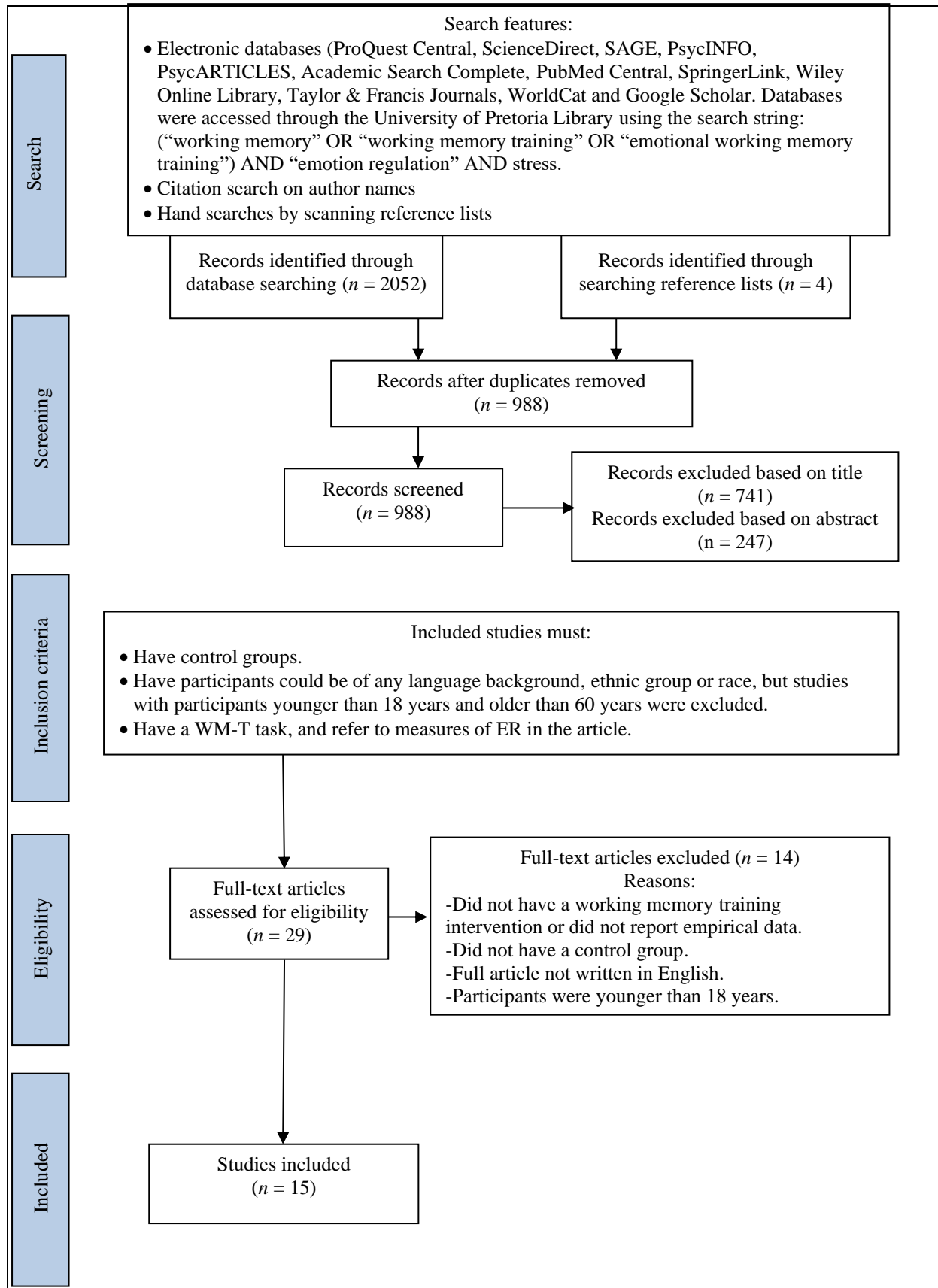
The stages are:

- First stage – a scoping search was conducted to search for primary studies on databases covering topics relevant to this study.
- Second stage – a database search using the identified search terms was conducted and documented (see Appendix B).
- Third stage – a search of bibliographies and reference lists was done and identified key citations as well as using manual searching of relevant journals.
- Fourth stage – verification and checking of the indexing of relevant papers that have been apparently missed by search strategies.
- Fifth and last stage – included the eligible studies to be assessed for quality standards and bias, and coding.

During the third stage of the search for eligible studies, the researcher reviewed a transdiagnostic review by Barkus (2020) which could not be included in the eligible studies as it was not a single empirical study. The review investigated the efficacy of WM-T for ER outcomes across 18 studies.

**Figure 10**

*The Selection of Working Memory Training Studies following the PRISMA Flow Diagram*



The researcher was only able to use four of the 18 studies as the remaining 14 studies could not be included in the present study for various reasons. Four could not be accessed via the database search; five investigated WM-T in psychological disorders not directly related to ER; two investigated children and adolescents; and three studies made no direct reference to ER. Another study by Deng et al. (2021), which was eligible for inclusion in the selected studies, used five references in support of ER outcomes following WM-T. These five references were also examined and the researcher only found two of those studies to be eligible. The remaining three studies were excluded from the eligible studies for various reasons: one was inaccessible due to the full article only being available in Chinese, despite an exhaustive database search to attain it; one is a transdiagnostic review by Barkus (2020) investigating the effects WM-T on ER, which has been used in the conceptual framework of the present study; and one is an article discussing the work done by Schweizer et al. (2013).

Reflecting on these stages, the researcher considered implementing relevant techniques applicable to this study. The collection, abstraction, and compilation followed a rigorous and prospectively defined objective process. A total of 15 studies were included after screening studies for eligibility.

### **3.5.5 *The Extracted Data***

The final list of selected eligible studies was guided by the research question. The included studies 15 were organised and separated into three categories to simplify analysis and curtail confusion regarding WM and ER and the outcomes of WM-T on ER. Each table lists the studies according to the author(s), year of publication, in which country in which the study was conducted, details regarding the participants, the type of program used in the trial(s), and the title of the study. The researcher conducted follow-up searches to ensure that new publications, or publications that could have been missed, were included.

The 15 selected studies were placed in chronological order and categorised as follows: Table 4: includes 7 studies using WM-T pertaining to the relationship between WM-ER whereby using WM-T as a tool in the investigation.

Table 5: includes 4 studies investigating WM-T for ER outcomes.

Table 6: includes 4 studies that use eWM-T to improve affective states and ER.

To check that the studies were extracted in a consistent manner, the researcher requested that the University of Pretoria's supervisor selects a random sample from the selected studies and cross-check them with the results of the researcher.

The researcher ensured that multiple publications of the same studies were not used as that would bias results. The studies that were included and excluded were accurately recorded in a data extraction from (Appendix C). Studies come from diverse countries, including the United Kingdom, China, the United States of America, Belgium, Canada, and South Africa. The 15 studies selected are analysed in Chapter 4.

### 3.5.6 Study Quality Assessment

The researcher utilised the adapted CASP tool for quantitative articles which consists of 11 items from Laher and Hassem (2020). The highest assessment score for quantitative studies was 11, and the cut-off score for inclusion was four. The adapted CASP tool was used to assess the quality of the articles included (see Appendix D). Table 7 expresses the potential risk of bias and the quality of the articles. The researcher noted the overall quality of the studies after the analysis for the potential risk of bias and quality of the eligible articles. The cut-off score was 4 and the maximum score was 11. The studies had scores between seven and 11 and the researcher was satisfied with the overall quality of the studies.

Figure 11 is a funnel plot representation of the quality of the selected studies from the highest score to the lowest score. The researcher noted that several particular quality assessment questions were lacking positive results after conducting the quality assessment. The researcher used a funnel plot presentation as an indication of which questions met quality criteria most frequently to the least frequently (see Figure 12). The plot yielded the following information:

Question 1: Clear aim: 100%

Question 2: Appropriate methodology: 100%

Question 6: Justification of research methods: 100%

Question 9: Rigorous data analysis: 100%

Question 3: Appropriate research design to address the aims: 67%

Question 5: Data collection: 67%

Question 8: Statistical technique of analysis: 67%

Question 11: Clear statement of findings: 67%

Question 4: Appropriate recruitment strategy: 53%

Question 7: Consideration of ethics: 53%

Question 10: Reliability and validity of psychometric instruments: 47%

**Table 4**

*List of Studies Utilising Working Memory Training for Investigating the Relationship Between Working Memory and Emotion Regulation*

Name of Author(s)	Year	Country of Study	Sample	Participant Age Range	Training Tasks	Title of Study
Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A.	2008	USA	(Study 4) 63 Participants 38 Females 25 Males	Undergraduate students Ages 18 to 23	Expressivity Questionnaire (BEQ) WM test (OSPAN) UWIST Mood Adjective Checklist	Working memory capacity and the self-regulation of emotional expression and experience.
Schmeichel, B. J., & Demaree, H. A.	2010	USA	102 Participants 77 Females 25 Males	Undergraduate students	Affective schedule: (PANAS) WM tests (OSPAN; AOSPAN) Crystallised Intelligence 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	USA	80 Participants 72 Females 8 Males	Undergraduate students $M_{Age} = 23$ years	Mindful Attention Awareness Scale (MAAS) ER questionnaire (ERQ) WM test (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	USA	41 Participants 41 Females (all mothers) Married: 9 Single: 29 Separated: 1	$M_{Age} = 28$ years	WM test (CBTT; WAIS-IV BDS) ER questionnaires (ERQ; DERS)	Investigating the relationship between working memory and emotion regulation in mothers.

Name of Author(s)	Year	Country of Study	Sample	Participant Age Range	Training Tasks	Title of Study
			Not reported: 2			
Yoon, K. L., LeMoult, J., Hamedani, A., & McCabe, R.	2018	Canada	45 Participants 29 Females 15 Males	$M_{\text{Age}} = 29$ years	WM task (RSpan) Social Stress Test (TSST) Depression questionnaire (BDI-II) Worry Questionnaire (PSWQ) Ruminative Responses Scale (RRS)	Working memory capacity and spontaneous emotion regulation in generalised anxiety disorder.
Peckham, A. D., Johnson, S. L., & Swerdlow, B. A.	2019	USA	59 Participants 31 Females 28 Males	$M_{\text{Age}} = 28$ years	Psychiatric diagnoses interview (SCID-IV) Mania scale (YMRS); Depression scale (MHRSD) ER questionnaire (ERQ) Rumination subscale (RRS) WM 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 $M_{\text{Age}} = 25$	WM test (AWMA) Resilience Measure (RRC-ARM) Resilience Interview	Working memory and psychological resilience in South African emerging adults.

*Note.* This table of studies includes 7 trials that are primarily investigating the relationship between WM and ER by utilising WM-T training tasks to test for the interaction of WM and ER as the outcome of the trial.

**Table 5**

*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 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	Attention task (ANT-S) ER Task; WM-T 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 - 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 (WNIC; CRC; 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 tasks ( $n$ -back task; 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	WM-T task (Running Memory Task) ER questionnaire (ERQ)	Working memory training improves emotion regulation in drug abstainers: evidence from frontal alpha asymmetry.

**Table 6**

*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 Tasks	Title of Study
Pe, M. L., Koval, P., & Kuppens, P.	2012	Belgium	95 Participants 59 Females 36 Males	Undergraduate students $M_{\text{Age}} = 19$	Depression measure (CES-D) Subjective well-being measures WM updating task (emotional $n$ -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	$M_{\text{Age}} = 23$	eWM-T Task (Dual $n$ -back task) Placebo WM 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 $M_{\text{Age}} = 23$	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 $M_{\text{Age}} = 22$	WM-T tasks (dual dimension $n$ -back; Spatial 2-back) Depression Anxiety Stress Scales (DASS) Cognitive ER 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.

**Table 7**

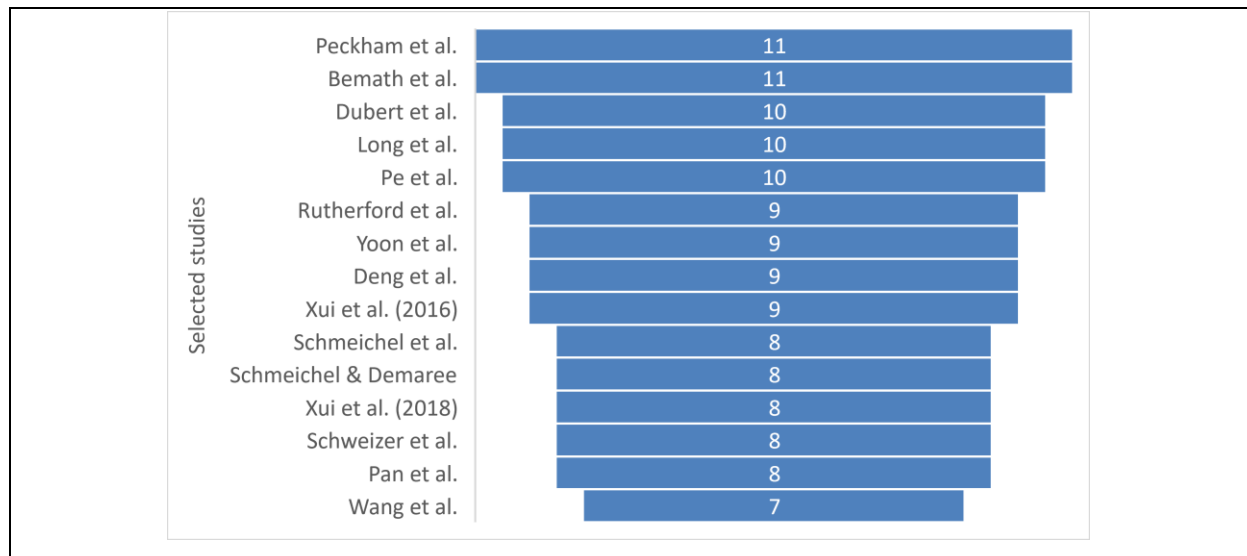
*Analysis of the potential risk of bias and quality of the eligible articles*

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 et al. (2018)	✓	✓	-	-	✓	✓	✓	✓	✓	-	✓	8
Wang et al.	✓	✓	✓	-	✓	✓	✓	-	✓	-	-	7
Long et al.	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	10
Deng et al.	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	9
Pe et al.	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	10
Schweizer et al.	✓	✓	-	✓	✓	✓	-	✓	✓	-	✓	8
Xui et al. (2016)	✓	✓	-	✓	✓	✓	✓	✓	✓	-	✓	9
Pan et al.	✓	✓	-	✓	✓	✓	-	✓	✓	-	✓	8

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

**Figure 11**

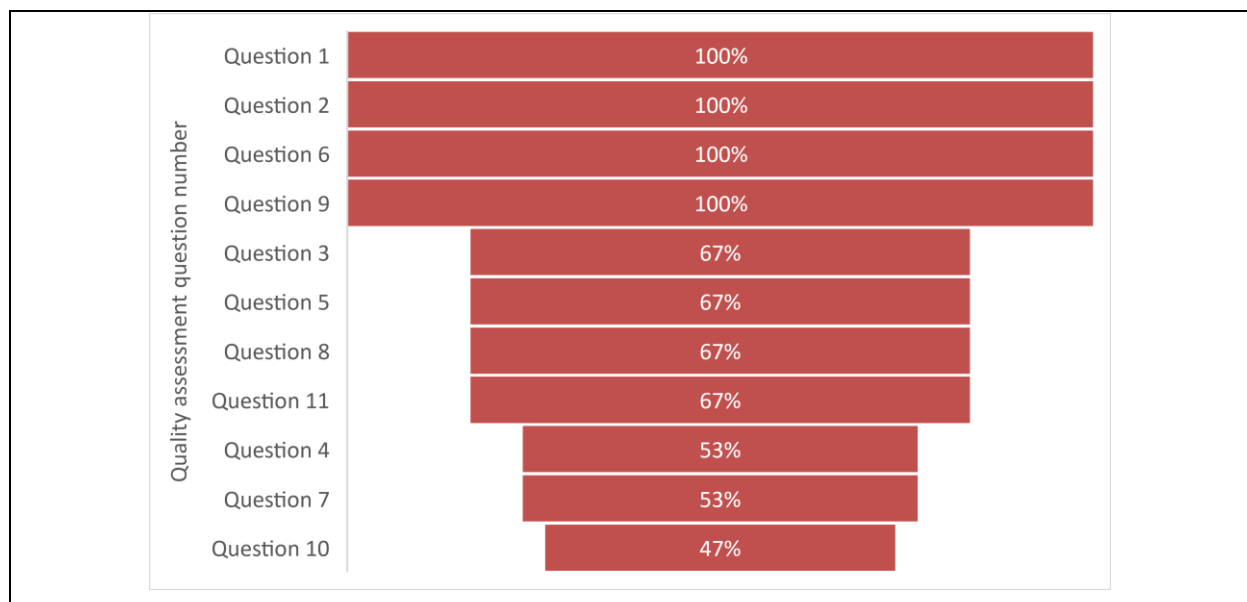
*Overall Quality Assessment Ratings of Selected Studies*



*Note.* The cut-off score was 4 and the maximum score was 11.

**Figure 12**

*Frequency of Quality Assessment Questions Being fulfilled by Selected Studies*



The researcher interpreted the results from the analysis of the study quality assessment, giving considerable attention to Question 10. This question assessed if the study discussed or analysed the reliability and validity of the instruments used for psychometric

testing or tasks. Another two questions were of concern to the researcher (Question 7 and Question 4). Both of these questions alluded to ethics and both yielded a score of 53%. These issues will be fully discussed in Chapter 4, Section 4.5. Also, two studies (Bemath et al., 2020; Pe et al., 2012) did not measure ER directly but did measure ‘subjective well-being’ (in that positive and negative emotions were psychometrically measured) (Pe et al., 2012) and resilience (in that the study had noted evidence of the implication of EF with resilience as EF are implicated in both behaviour and ER (Bemath et al., 2020)).

Overall, the quality assessment yielded good quality assessment ratings for the selected studies, with two major concerns being the explanation of the reliability and validity of the instruments used as well as the ethical considerations given to the recruitment strategies and approval from ethics committees. The researcher presumes that this information may influence bias and will give more consideration to this in the limitations of the selected studies covered in Chapter 4.

### ***3.5.7 Analysis and Interpretation of Studies***

This systematic exploratory review used qualitative data analysis for the application of various methods of analysis such as interpretive and integrative strategies (Laher & Hassem, 2020). For the analysis of the selected studies, attention is drawn to the PVO strategy for systematic exploratory reviews (Silva et al., 2017) to elucidate the disparity found within and across studies. The PVO strategy informs the analysis of the population (contextual information), variables (the WM-ER dyad and stress), and the outcomes of the studies. The limitations of WM-T associated with ER that were extracted from the selected studies are included in the analysis. For the purpose of analysis, the researcher strictly adhered to the steps encompassing the methodology of systematic exploratory reviews as they pertain to the selection of studies following predefined selection criteria and a quality assessment to detect bias.

### ***3.5.8 Dissemination of Findings***

In line with the aims of this research, the systematic exploratory should be eligible to be published in an academic journal through the University of Pretoria in order to communicate the findings for future research agendas.

## **3.6 Ethical Considerations**

Researchers have the responsibility to ensure that public reports of their research are accurate and honest (Gravetter & Forzano, 2010). The requirements of a systematic review

ensure validity and ethical consideration (Kitchenham, 2004). The validity of a research study is the degree to which the study accurately answers the question it was intended to answer (Gravetter & Forzano, 2010). The reliability of a measurement procedure is the stability or consistency of the measurement. If the same individuals are measured under the same conditions, a reliable measurement procedure produces identical (or nearly identical) measurements (Gravetter & Forzano, 2010). The sources of information for this systematic-exploratory review were obtained from consulting various reliable resources, including the University of Pretoria's online library for academic journals and legal databases. The information was gathered in an ethical manner, by listing and providing all the references for the information used and there was no form of plagiarism in the collecting of theoretical information for the literature review. No unethical practices of using pirated articles from illegal websites were used in the information gathering for this review.

The researcher made a concerted effort to remain unbiased and impartial throughout the duration of undertaking the dissertation. The results may be different when an experimenter's expectations affect the outcomes of the study (Gravetter & Forzano, 2010). To overcome personal bias, the researcher paid careful attention to the studies selected for inclusion for review as qualitative research includes methods, plans, and structure for selecting relevant studies for inclusion.

### **3.7 Conclusion**

The characteristics and requirements of both a systematic and exploratory review were explained at the beginning of this chapter. The research methodology for this systematic-exploratory review adopted the eight stages of a systematic review to ensure that this review was conducted thoroughly and in an unbiased manner with the studies and literature that it included. The methodology expressed the process of extracting the studies and literature for the systematic exploratory review and provided tabulated lists of the studies that were reviewed for the purpose of analysis. Ethical considerations for the systematic-exploratory review were also explicitly stated. The sample of empirical studies is analysed in the following chapter.

## Chapter 4: Analysis and Results

### 4.1 Introduction

The research methodology in Chapter 3 detailed the research design, research strategy, sampling procedures, and review protocol that were applied in this study. For the purpose of analysis, the researcher strictly adhered to systematic review protocols for the selection of the studies that were found to be eligible. The 15 studies were selected according to predefined eligibility criteria and were assessed for their quality in order to avoid bias. In the analysis of the selected studies, attention is drawn to the PVO strategy for systematic exploratory reviews (Silva et al., 2017). The PVO strategy informs the analysis of the population (contextual information), variables (the WM-ER dyad and the influence of stress on the WM-ER dyad), and the outcomes of the studies. The implications of WM-T for WM and ER, which form a focal part of the research and is stated as part of the research topic in the title of the study, are included in this chapter. This section is in line with aim 3 by integrating the analysis with the theoretical and conceptual framework. Chapter 5 provides a brief discussion and the conclusion to the study.

### 4.2 Population

The population includes the contextual information regarding the samples (participants) from the selected WM-T studies. A total of 952 participants were included in the 15 studies.

#### 4.2.1 Contextual information

Figure 13 is a diagrammatic representation of the different contextual factors that were used for the analysis of the population. The researcher extracted the contextual information from the selected WM-T studies and tabulated the information for analysis (see Table 8). The contextual information is discussed with its relevance to the tabulated data.

- Age of Participants

In terms of the selection criteria of the present study, the researcher chose to include adult participants between the ages of 18 and 60 years. The researcher made an exception with one study which had an age range of 17 to 24 years ( $M_{age} = 20$ ). For the analysis, the researcher 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 older than 45 years.

**Table 8***Analysis of Contextual Information*

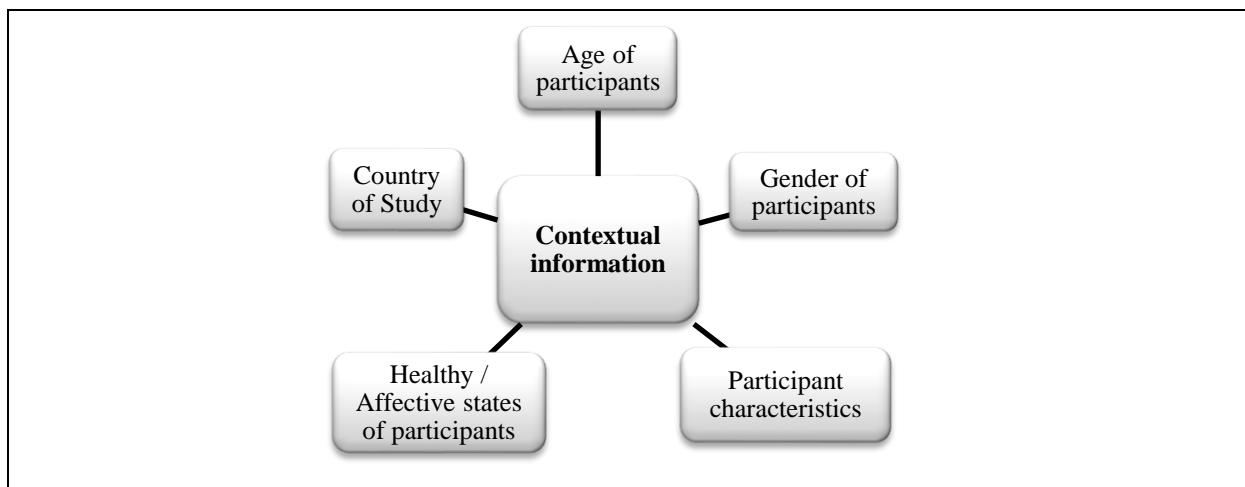
Data Sources	Population																
	Contextual Information																
	Age of Participants		Gender		Participant Characteristics				Healthy / Affective States			Country of Study					
	18 <26	27<44	M	F	University Students	Mothers	Drug Abstiners	General Public	Healthy	Psychological Disorder	Not Mentioned	USA	China	SA	UK	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				
<b>15</b>	<b>11</b>	<b>4</b>	<b>334</b>	<b>618</b>	<b>10</b>	<b>1</b>	<b>1</b>	<b>3</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>6</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>
<b>Percentage</b>	<b>73</b>	<b>27</b>	<b>36</b>	<b>67</b>	<b>67</b>	<b>7</b>	<b>7</b>	<b>20</b>	<b>33</b>	<b>33</b>	<b>33</b>	<b>33</b>	<b>40</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>

Eleven of the studies included participants in the 18 to 26 cohort, compared to the mere four studies having participants in the 27 to 44 cohort. None of the studies reported the reason(s) for choosing participants of a particular age.

The researcher noted that preference was made by researchers for choosing participants between 18 and 26 years old.

### Figure 13

*Diagrammatic Representation of the Analysis of Contexts of the Studies*



#### • Gender of Participants

The gender of participants was not evenly distributed in the studies as 618 females outweighed the 334 males. However, one study only included males but the researchers did not validate their reason(s) for this choice, yet it was mentioned as a limitation in the study. The researcher surmised that the large number of female participants was due to them being more willing to participate in the studies, as males could have either rejected the offer to participate or dropped out after the screening process. None of the studies explicate the reasons for more female participants over males, except for one study that only included female participants due to the study investigating mothers.

#### • Participant Characteristics

The characteristics of the participants were divided up into four groups (university students, mothers, drug abstainers, and those not specified were grouped as the general public) for analysis. University students was the most prominent sample characteristic with 10 studies using this sample group. University students were recruited at the universities, which

made the task of recruitment and selection slightly easier. One study used participants that were mothers, one study used drug abstainers, and the other three studies used the general public. Participants from the general public were recruited in various ways, by either responding to online advertisements, student bulletins, belonged to volunteer panels or were recruited from outpatient clinics or hospitals where participants with psychological disorders were sought by researchers.

#### • Healthy or Affective States of Participants

Five of the studies used healthy sample groups that were explicitly chosen by the researchers following assessments of psychological disorders, drug or alcohol addictions, or having any history of mental illness. Five of the studies recruited participants with various psychological disorders, such as GAD or state anxiety disorders, mania (BP I Disorder), and depression. In the other five studies, the researchers did not make any reference to whether or not participants had any psychological disorders at the time of the trial, had a history of any psychological disorder, had any addictions, whether they were healthy, or had undergone any psychological assessments in the recruitment process before the trial. In those samples where healthy or affective states were not specified, the researcher presumed them to be generally healthy subjects.

#### • Country of Study

The studies came from a total of six different countries, with researchers from the USA and China producing the most studies in the sample, with five and six respectively. The former produced studies between 2008 and 2019, with the latter producing studies between 2018 and 2021. It should be noted that the USA did not feature in any WM-T study for ER outcomes but that all their studies in the sample investigated the relationship between WM and ER. China produced all four studies included in Table 5 where WM-T was investigated for ER outcomes, and two in Table 6 investigating eWM-T for ER outcomes. However, the earliest trial investigating eWM-T for ER outcomes came from a study in Belgium in 2013. Studies produced by researchers from other countries include one from South Africa, one from the UK, and one from Canada.

### 4.3 Variables Featured in the Selected Studies

Two variables were chosen for analysis: the WM-ER dyad and stress. These two variables are in line with the topic, research question, and the first two aims of the present study. The contextual framework in Chapter 2 serves as a foundation for these variables to be

clarified and understood for their role in WM-T studies. The researcher chose to extract the information regarding any discussion on these variables from each study to detect any discrepancies or patterns across studies, or differences or similarities to the contextual framework. The variables that featured in each of the selected studies were tabulated and are conveyed in Table 9, which categorically separated the studies according to their categorisation found in Tables 4, 5, and 6 respectively.

**Table 9**

*An Extraction of the Variables Featured in the Selected Studies*

Data Sources	Variables	
	WM-ER Dyad	Stress
	<b>Studies Utilising WM-T for Investigating the Relationship Between WM and ER</b>	
1. Schmeichel et al. (2008)	The study proposed that WM is important for success at ER. Study 4 hypothesised that WM assists in effectively adopting neutral appraisals of emotional information.	The study related WM, as potentially benefitting real-world efforts at ER, with previous research where appraisal used during a stressful task in unemotional terms resulted in less negative affect and better recollection in the suppression of emotional responses, which underscores the potential benefits of WM for everyday ER.
2. Schmeichel and Demaree (2010)	The study hypothesised that WM contributes to spontaneous ER. Findings supported the WM-ER dyad in that participants with efficient WM automatically engaged in self-enhancement.	The study suggests that future investigations should examine ER in other contexts such as in the workplace and stressful environments, and in response to other emotional experiences.
3. Dubert et al. (2016)	In the investigation of the mechanisms underlying dispositional mindfulness, WM, and ER strategies of reappraisal and suppression, a mediation path model was proposed explaining a relationship between mindfulness and ER that may be facilitated by the attention function of WM.	WM may only be actively engaged during stressful experiences requiring ER using reappraisal. Further investigation is needed to determine whether ER actively engages WM only during stressful events or during non-stressful events. Stress may not have adversely influenced WM and ER over time.
4. Dubert et al. (2016)	The study investigated whether measures of visuo-spatial WM and verbal WM relate to ER. The researchers anticipated WM task performance would increase cognitive reappraisal and decrease emotional dysregulation.	The authors used a sample of mothers due to motherhood being a stressful time with many challenges potentially exclusive to the caregiving role. WM, alongside stress physiology, may facilitate the relationship between early difficulties and maternal sensitivity.

Data Sources	Variables	
	WM-ER Dyad	Stress
5. Yoon et al. (2018)	The study examined the link between cognitive control and levels of unprompted rumination. Specifically, whether WM in the presence of negative distractors, controls the relationship between GAD and levels of rumination in response to an acute stressor.	A task was added into the trial to induce stress in patients to investigate the mechanisms underlying pervasive thinking in GAD and rumination.
6. Peckham et al.(2019)	The study examined whether WM is linked to ER in BD and whether the WM-ER dyad can explain changes in symptoms over time.	The absence of a relationship between WM and rumination suggests that the relationship may only develop under stressful conditions. Further investigation is needed to test the hypothesis that changes in cognitive performance under stressful conditions contribute to emotion dysregulation in patients with BD.
7. Bemath et al. (2020)	The study investigated the role of WM in resilient behaviours. WM was investigated for its theoretical ability to enable individuals to regulate emotions, thereby facilitating resilience.	Stress was not directly referred to in the study, however, the study referred to the exposure to adversity potentially disrupting normal development or functioning and that psychological resilience is needed to successfully overcome hardships.
	<b>Studies Investigating WM-T for ER Training Gains</b>	
8. Xui et al. (2018)	The study indicated a connection between ER and attentional control in WM. The orientation function is the attention network mechanism that selects and filters external information. Reappraisal is required to change the emotional meaning and use updating to form new meanings; however, WM affects the selection and allocation of resources used in the orientation function.	The article suggests that future research must involve participants with psychiatric disorders, such as PTSD, depression, and anxiety disorders, which are associated with ER deficits.
9. Wang et al. (2019)	The study found that the neural mechanisms of WM improving ER are relative to WM requiring the participation of the PFC. Through WM-T, PFC control ability is enhanced, thus changing the cognitive reappraisal of anxious individuals. Both WM and ER involve processes of updating, suppressing, and shifting or transforming. Therefore, WM can be seen as the cognitive basis of ER.	The study did not mention stress as a variable, however, the study used high-anxiety individuals as participants.
10. Long et al. (2020)	Researchers found that the suggestion of cognitive enhancement could play an important role in improving emotion and behaviour. Expectation and Placebo effects are facilitated by brain reward circuitry in which the expectation of a reward triggers	The study made no reference to stress.

Data Sources	Variables	
	WM-ER Dyad	Stress
	dopamine release in the nigrostriatal system. Placebo involves many systems in the PFC, nucleus accumbens, and amygdala, and increases functional connectivity between them. These regions are also used in ER; therefore, placebo training activates these brain regions, which enhance ER.	
11. Deng et al. (2021)	The study describes the frontoparietal brain network as being crucial for attentional control and updating in WM. WM-T may improve attentional control because the training group would avert their attention away from negative information and would therefore have more cognitive resources for ER. WM-T may have lessened the activity of the amygdala and increased the top-down control of the PFC over the amygdala, therefore making ER more spontaneous.	The study made no reference to stress.
	<b>Studies Investigating eWM-T for ER Training Gains</b>	
12. Pe et al. (2012)	Certain forms of ER require focusing on or inhibiting specific emotionally-laden information in WM. Retaining and updating positive stimuli in WM were linked to higher levels of life satisfaction and experiencing more positive than negative emotions in daily life.	Although stress was not directly mentioned in the study, the study did find that the relationship between subjective well-being and updating of positive information goes beyond any effects that depression might have on this relationship.
13. Schweizer et al. (2013)	Following behavioural and fMRI measures, ER gains were associated with greater activity in the targeted frontoparietal demand network along with other brain regions implicated in affective control, notably the ACC. ER and eWM share the same underlying neural circuitry in the fronto-parietal demand network, including the medial and lateral PFC and inferior parietal cortex. This network is crucial for downregulating emotional activation in emotion processing areas, such as the amygdala. Neural transfer increased activation in the ACC during ER, which is responsible for downregulating emotional distress through the use of many cognitive control strategies. The mechanism of action is likely to be the ACC's coupling with the amygdala, and the strength of this coupling is predictive of ER success.	The findings underscore the promise of cognitive training protocols using emotional stimuli for emotional control in healthy populations. Such control is vital for professionals in stressful environments.

Data Sources	Variables	
	WM-ER Dyad	Stress
14. Xiu et al. (2016)	The study supports the cognitive basis for the possibility that when negative emotional information is encountered, individuals would disengage their attention and update the negative emotional information in WM. This would disable the dysfunctional cycle from continuing and decrease emotional rumination. Therefore, the availability of attention resources increases for handling events in daily life, thereby improving the emotional experience, quality of life, and subjective well-being.	Although the study did not directly refer to stress, the researchers stated that ER is closely related to mental health and, therefore, ER becomes crucial for a research approach to illustrate how cognition affects emotion.
15. Pan et al. (2020)	When the researchers compared eWM-T to general WM-T during laboratory reappraisal, they surmise that increased inhibition requirements of eWM-T may improve ER. Moreover, distraction was thought to involve less cognitive demand and top-down control than reappraisal and was also found to be less impaired in patients with anxiety. eWM-T helped anxious individuals to decrease attentional bias and focus on non-emotional stimuli by ignoring emotional stimuli. Repetitive exposure of negative irrelevant stimuli was designed to re-balance attentional focus. This may improve resistance to emotional distraction, which then automatically transfers to ER which is spontaneous. On a neural level, this may rely less on fronto-parietal networks directly related to WM and may rely more on the control of the medial PFC and regions related to ER (the amygdala).	The study included the following literature related to stress. The reassessment of a stressful experience requires the flexible employment of WM in two modes: one mode must restrain the existing negative evaluation while the other mode simultaneously draws reasonable interpretation from experience to update the original representation (Pe et al., 2013, as cited in Pan et al., 2020). Reappraisal as the adaptive strategy for coping with stress can produce lasting positive effects (Goldin et al., 2008, as cited in Pan et al., 2020) and is a key factor in guard against anxiety (Hofmann et al., 2009, as cited in Pan et al., 2020). The self-report scales used in the trial included a Depression Anxiety Stress Scale (DASS) used to measure general mood with subscales measuring depression, anxiety, and tension stress.

#### 4.4. Outcomes

The outcomes from each trial are extracted and summarised in Table 10 which categorically separated the studies according to the categorisation found in Tables 4, 5, and 6 respectively.

**Table 10***Compilation of the Main Outcomes of the Selected Studies*

Data Sources	Outcomes
	<b>Studies Utilising WM-T for Investigating the Relationship Between WM and ER</b>
1. Schmeichel et al. (2008)	Researchers found that individuals with efficient WM are better at ER than those with weaker WM. Moreover, the study found a positive connection between WM and the suppression of emotions and less emotional expression following reappraisal while watching emotionally charged videos. Study 4 found that participants with efficient WM expressed and experienced less emotion when they attempted to evaluate emotionally charged information in unemotional terms. Adopting neutral evaluations may minimise or prevent responses to both positive and negative information.
2. Schmeichel and Demaree (2010)	The findings showed that spontaneous or uninstructed (which is implicit) ER is possibly more prevalent in daily life than attempting to improve ER following instructions (which is explicit). The findings provide valuable evidence that WM is important for spontaneous and uninstructed ER. Moreover, individuals who are skilled at multitasking (better WM) are better at performing cognitive tasks and managing their emotional responses (ER). Furthermore, those with efficient WM experienced fewer negative emotions in response to fictitious negative feedback and responded with higher levels of self-enhancement.
3. Dubert et al. (2016)	The study found that mindfulness had a weak but significant relationship with ER using reappraisal but a non-significant relationship between mindfulness and ER using suppression. Non-significant results for the relationship between mindfulness, ER, and WM were found.
4. Dubert et al. (2016)	While the study found evidence of associations between visuo-spatial WM and ER, there was a non-significant relationship between verbal WM and ER. Greater visuo-spatial WM related to increased reliance on reappraisal and predicted a general decrease in emotion dysregulation.
5. Yoon et al. (2018)	Findings showed that a poor WM in the presence of negative distractors related to increased levels of rumination in GAD following a stress-induced task. This is possibly due to poor WM hindering cognitive control over irrelevant stimuli which makes it challenging for individuals with GAD to disentangle their thoughts from negative information, leading to invasive and persistent thoughts.
6. Peckham et al. (2019)	The study revealed that WM had no relation to ER in that poor WM did not intensify the effects of problematic ER. However, individuals with poor WM that used less suppression predicted higher levels of mania in BD. Levels of depression or mania were not related to reappraisal, regardless of WM ability. Findings did not support the idea that ER warrants poor WM.
7. Bemath et al. (2020)	Researchers found non-significant quantitative findings suggesting that WM affects resilience, although significant findings showed a relationship between verbal WM and spiritual resilience. The qualitative analysis captured the influences that defined the link between WM and resilience, which include the actions of goal-directed behaviour, problem-solving, and reappraisal.

Data Sources	Outcomes
	<b>Studies Investigating WM-T for ER Training Gains</b>
8. Xui et al. (2018)	Findings suggest that WM-T can improve ER. The researchers state that the orientation function in the attention network could potentially contribute to the improvement in ER.
9. Wang et al. (2019)	Researchers found that WM-T improves the ability of individuals to use reappraisal and that WM-T could be used as an intervention for improving ER in individuals with GAD.
10. Long et al. (2020)	Results showed that participants in the 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.
11. Deng et al. (2021)	The study showed that WM-T improved ER in drug abstainers. This finding was based on the training group adopting more spontaneous ER strategies (reappraisal) and increased updating ability in WM related to faster disengagement from the negative stimuli.
	<b>Studies Investigating eWM-T for ER Training Gains</b>
12. Pe et al. (2012)	Subjective well-being is linked to the efficient processing of positive information using updating.
13. Schweizer et al. (2013)	Findings showed that WM-T with emotional stimuli resulted in marked behavioural improvement on the trained task. eWM-T resulted in clear behavioural and neural transfer to ER, therefore significantly improving ER.
14. Xiu et al. (2016)	The study found that WM-T could transfer to ER in that improved WM updating capability is beneficial to ER. This was revealed after eWM-T was conducted on participants and the high-frequency heart rate variability (HF-HRV) of participants increased, meaning that inhibition of the autonomic nervous system had been improved. This inhibition is useful for regulating negative information and stabilising fluctuations in mood.
15. Pan et al. (2020)	The study presented findings indicating that both WM-T and eWM-T improved ER following instruction (explicit ER). While general WM-T improved explicit ER, eWM-T further improved spontaneous (implicit) ER. Furthermore, general WM-T can increase the reappraisal ability of individuals with anxiety following training, while the addition of emotional distraction in eWM-T can further balance spontaneous attentional control and decrease negative attention bias. Therefore, ER improvements and decreased attentional bias following eWM-T relieves anxiety, and thus provides higher clinical application value. The researchers observed remarkable emotion-related improvements following general WM-T in anxious individuals, which included decreases in anxiety and tension stress scores.

## 4.5 Implications of Working Memory Training

This section integrates the results from the analysis of selected studies with the theoretical and conceptual framework to provide a discussion highlighting similarities,

discrepancies, or both. In the research analysis, the variables (the WM-ER dyad and stress) are discussed in terms of their prevalence in WM-T to facilitate functioning of ER. In certain instances, the WM-ER dyad is similar when linking the research analysis with the literature review. However, a discrepancy exists between the research analysis and the conceptual framework concerning stress. The methodological shortcomings found in the selected studies are also included in this section.

#### ***4.5.1 The Working Memory-Emotion Regulation Dyad as a Variable***

Consistent with the first aim investigating the WM-ER dyad, WM was significantly associated with greater ER as the higher-order executive skills that characterise WM are related to ER (Evans et al., 2016). Although the relationship between WM and ER has been well researched, trained WM and the desired outcome of improved ER following WM-T remains conflicted in research. Some 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). Participants with higher WM spontaneously engaged in self-enhancement and less negative effects following negative feedback in the study by Schmeichel and Demaree, 2010. Spontaneous ER refers to implicit ER, which is automatic and related to attentional ability, which is used to successfully carry out goal-directed behaviour despite distractions (Klumpp et al., 2017). Spontaneous and uninstructed ER is possibly more prevalent in daily life compared to attempting to improve ER by following instructions (Schmeichel & Demaree, 2010). Schmeichel and Demaree (2010) postulate that efficient WM involved spontaneous ER more effectively, and that individuals did not simply follow instructions better than those with lower WM capacity did. Moreover, individuals who are better at juggling multiple streams of information are more skilled at managing their emotional responses (Schmeichel & Demaree, 2010). However, 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). Given this information, WM and ER may seem to be a unitary construct but this notion is challenged in intervention research.

The primary goal for WM-T interventions is to show an improvement from a specific training task to a generalised improvement in ER, however, achieving this has been problematic (Engen & Kanske, 2013). Achieving improvement in ER following a specific task is problematic because of the contrast in the levels of processes being studied (Engen &

Kanske, 2013). The basic abilities that are responsive to WM-T, such as attentional control and WM, are not as complex as ER that needs to improve in real life for the intervention (WM-T) to be effective (Engen & Kanske, 2013). Goldberg and Goldberg (2009) point out an important discrepancy between the way memory is used following an experimental memory task and the way memory is used in real life. In real life, the decision of what to remember needs to be made but in an experimental memory task, the decision of what to remember is already made when the researcher instructs the participant to remember specific stimuli. Therefore, the decision-making process activated in the frontal lobes is removed and the value of the WM task is lost (Goldberg and Goldberg, 2009). In real life, the ability to remember involves WM and the frontal lobes, but experimental WM tasks do not involve those processes or the full activation of the frontal lobes (Goldberg & Goldberg, 2009).

As Klingberg (2008) explains, we need not only do the right kinds of exercise but also do them in a way that brings about lasting change, which is to say at the right level of difficulty and with sufficient intensity for a sufficient length of time. Logging onto the Internet and playing a few games once a week is unlikely to have any enduring effect on visual WM. Brady et al. (2019) used a real-life approach to studying visual WM, which they posit is the kind of approach that is important for further research into WM because we function, live, and work in the real world. It is, in essence, these real-life complexities that either enhance our capacities or limit us further, or give us new insight into how we temporarily store information. In experiments using simple stimuli, WM is thought to have a limited capacity regardless of how much time participants are given to remember items, however, by contrast, experiments using WM tasks in real life have found the absence of an obvious limitation as individuals recalled more information if they were given more time (Brady et al., 2019). Stimuli used in real life also have the added advantage of using LTM or a form of more available long-term memories (Brady et al., 2019).

The function of memory as two distinctive and separate compartments, namely WM and LTM, each with unique definitions and functions, and using different areas of the brain, has been shown as overlapping and that LTM supports the functioning of WM (Schurgin, 2018; Sternberg, 2009). In LTM, it has been theorised that attaching meaning to real-world objects is the key factor that assists memory (Brady et al., 2019).

The researcher will discuss the neural underpinnings between WM and ER implicated in WM-T studies in more detail in the following section.

#### ***4.5.2 Neural Underpinnings of the Working Memory-Emotion Regulation Dyad***

The neural circuitry of WM and ER following eWM-T was first investigated by Schweizer et al. (2013). The study used behavioural and fMRI measures and found that the ACC coupled with the amygdala is responsible for improved ER (Schweizer et al., 2013). Moreover, Deng et al. (2021) posit that WM-T increases in neuronal activity in the PFC and that the shared neural network between the PFC and the posterior parietal cortex is involved in ER. Deng et al. (2021) indicated the efficacy of WM-T to improve ER in drug abstainers was the same as that of healthy individuals and individuals with other emotional disorders. The study also investigated the updating function of WM and found that the frontoparietal brain network is important for attentional control when participants were shown negative and drug-related stimuli, enabling them to disengage their attention from negative stimuli (Deng et al., 2021). Therefore, participants had access to more cognitive resources for ER as training had improved the proficiency of processing information (Deng et al., 2021). Moreover, Deng et al. (2021) stated that WM-T may have decreased amygdala activity in the training group as there were changes in the encoding, storage, and retrieval of information. Training also 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). A study by Klumpp et al. (2017) attempting to improve ER following Cognitive Behavioural Therapy (CBT) examined the ACC and the amygdala, which have been shown to be activated in various tasks predicting ER outcomes. Klumpp et al. (2017) found that there was more ACC activity and greater amygdala response in spontaneous regulation than regulation following therapy (using reappraisal). The study found that there were no significant effects for regulations following therapy. This study is similar to training WM to improve ER, in that both trainings attempt to improve ER through interventions, and investigating the difference between implicit and explicit ER.

The researcher found an important contradiction in studies that further implicates the WM-ER dyad in WM-T. Schweizer et al. (2013) included a placebo eWM-T task which was 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 contrariety between a growing body of studies like the one conducted by Schweizer et al. (2013) and the contradictory views of the efficacy of WM-T by investigating placebo or expectation effects

on ER. By using a pseudotraining WM-T task for ER outcomes, 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 in the brain which triggers dopamine projection into the nigrostriatal subsystem. To reiterate from the conceptual framework provided in Chapter 2, dopamine is used in the gating function of WM in the striatum (Morrison & Chein, 2011; 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, ACC, and amygdala, and these same areas of the brain are implicated in ER (Long et al., 2020). Therefore, the expectation of training gains brings about the motivation to invest more effort to enable achievement, in which participants are activating cognitive control for positive outcomes and to evaluate and enact goal-consistent behaviours (Long et al., 2020). The expectation for training gains was also mentioned as a training limitation by Barkus (2020), who stated that reduced negative emotions could be brought about by participants' expectations that training will yield positive outcomes. Emotion and motivation are mental processes that share different brain regions (Crocker et al., 2013). 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, as 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).

#### **4.5.3 *Stress as a Variable***

Consistent with the second aim of investigating the influence of stress on the WM-ER dyad, stress was found to have a moderating effect on the WM-ER dyad and stress has been related to both maladaptive WM and ER, which is common across most mental health disorders (Barkus, 2020). However, despite the extensive amount of available literature about stress and its detrimental effects on WM and ER, stress was included as a variable in only 3 of the sample of studies. Of these studies, 2 were found in the first category of studies that used WM-T as a tool to investigate the relationship between WM and ER, and the other 1 study

used a Depression Anxiety Stress Scale (DASS) to measure general mood. An acute stressor was added into 1 trial, and a sample of mothers was chosen in 1 trial due to motherhood being a stressful time. Stress was not included as a variable in any of the WM-T studies or eWM-T studies for ER outcomes. However, six studies made reference to stress in either the background or literature review of the study or in their recommendations to include stressful contexts in future studies. The other six studies made no reference to stress at all. This could be because studying the impact of stress relies on lab studies which have to be temporary and minor (Sanders, 2020). This weakens the validity of the studies regarding stress and requires more real-life stressful environments for research.

Furthermore, ER strategies are needed in stressful contexts where mental resources will be challenged by the context (Barkus, 2020). The amount of behavioural control over a stressor often dictates the significance of that stressor and influences the development of pathological behaviours following traumatic experiences (Kumar et al., 2013). Recently, researchers investigated a training approach to psychological adaptation in isolated, confined, and extreme environments for the South African Navy (Van Wijk & Martin, 2021). Psychological adaptation is broadly defined as the ability to adjust to change in the environment, in order to optimise personal functioning (Van Wijk & Martin, 2021). Psychological adaptation is reflected by three indicators: (a) task ability (quality of work output); (b) sociability (quality of interpersonal interaction); and (c) emotional stability (quality of self-regulation) (Van Wijk & Martin, 2021). A single factor that underpins all three indicators is ER, and as such, it can be used to operationalise psychological adaptation, in that individuals with more adaptive ER should be expected to manage their personal performance across work output, social interactions, and affective states effectively, especially under psychological demands (Van Wijk & Martin, 2021). This supports the idea that ER could be trained directly in stressful environments, however, it excludes the variable of WM and WM-T.

The researcher assumes that the reason why there is a paucity of research including stress in WM-T could be due to the additional variable of stress possibly affecting training outcomes (Raio et al., 2013) or that inducing stress in participants for experiments and trials may be impractical and unethical.

#### ***4.5.4 The Efficacy of Working Memory Training***

After a substantial number of studies investigating WM-T for ER training gains gained ground, Barkus (2020) conducted a transdiagnostic review investigating the transfer effects of

WM-T on ER across studies. Barkus (2020) surmised that training gains from WM-T to ER are caused by the cognitive and neural connection between WM and ER (Barkus, 2020). Barkus (2020) selected 18 studies that utilised computerised WM-T packages for ER outcomes. The researcher examined each study used in the transdiagnostic review and was only able to include 4 studies in the present study. The researcher found the review by Barkus (2020) to be lacking conclusive evidence on the efficacy of WM-T for ER outcomes. Another study by Deng et al., (2021), which was included in the selected studies, stated that WM-T has been proven to improve ER in both healthy populations and individuals with emotional disorders. Deng et al. (2021) used five references for that statement, yet the researcher was only able to find two studies eligible for the systematic review (see Section 3.5.4 for details regarding the selection of studies). Moreover, other reviews show contradictions in findings regarding the efficacy of WM-T to improve untrained tasks (Pappa et al., 2020).

Pappa et al. (2020) found moderate improvement on trained tasks in the same cognitive areas, but improvements to other cognitive areas had a non-significant effect. However, Barkus (2020) posits that WM-T could yield improvements on trained tasks or untrained tasks, even if they are small effects. Cognitive training improvements on a task are a *sine qua non* of training but the main goal is to show improvement in untrained tasks following a training intervention (Schweizer et al., 2013). Schweizer et al. (2013) stated that their findings showed marked behavioural improvements on the trained task and that eWM-T yielded significantly improved ER (the untrained task). However, through the meta-analysis of WM updating training (eWM-T) studies, Pappa et al. (2020) found that WM updating training (eWM-T) was shown to significantly improve trained tasks and produced reasonable near transfer effects but there was no evidence of improvements on the untrained task. This contradicts the results of the 4 studies using eWM-T for ER training gains included in the systematic review sample.

Pappa et al.(2020) postulate that contradictory findings are due to publication bias, where experiments with smaller samples display marked improvements after training, and these studies were more likely to have been published. Pappa et al. (2020) believe small samples to be problematic as the efficacy could be miscalculated. Although Pappa et al. (2020) found that WM updating training (eWM-T) showed improvement in cognitive performance in adults, the funnel plot was indicative of publication bias (Pappa et al., 2020). Experimenter bias threatens external validity because the outcomes of the trial may be influenced by the researcher's expectations (Gravetter & Forzano, 2010). Experimenter bias also threatens internal validity because the data may show a pattern that appears to be a real

treatment effect but was actually caused by the experimenter's influence (Gravetter & Forzano, 2010).

#### ***4.5.5 Cognitive Paradigms Used in WM-T Studies for Emotion Regulation Outcomes***

The operationalisation and measurement of WM and ER found in the various studies further implicate the WM-ER dyad and the efficacy of the studies. The researcher observed that an array of WM training tasks existed in the 15 studies used in the systematic review and that there are disparate cognitive paradigms used in studies (Pappa et al., 2020). Of the 15 studies, researchers administered 15 different WM measures which are listed in Table 11. Of the 15 WM measures, five were administered twice across studies. The remaining 10 WM measures were only administered once across studies. There is, evidently, a lack of standardisation of WM measures across studies.

**Table 11**

*Working Memory Training Tasks Used in the Selected Studies*

<b>Working Memory Training Task</b>	<b>Number of Times Administered Across Selected Studies</b>
1. OSPAN	2
2. AOSPAN	2
3. WAIS-IV BDS	2
4. Running WM task	2
5. Dual <i>n</i> -back	2
6.CBTT	1
7.RSpan	1
8.AWMA	1
9. <i>n</i> -back	1
10. Search Task	1
11. Running Memory Task	1
12. Emotional <i>n</i> -back	1
13. 2-back	1
14.Dual Dimension <i>n</i> -back	1
15. Spatial 2-back	1

The same lack of standardisation exists for ER measures. As for ER measures, a total of 12 different ER tasks were identified across the 15 studies which are listed in Table 12. The ER Questionnaire (ERQ) was administered four times across studies and the ER task was administered three times across studies. The remaining 10 ER measures were only administered once across studies.

**Table 12***Emotion Regulation Training Tasks Used in Selected Studies*

<b>Emotion Regulation Training Task</b>	<b>Number of Times Administered Across Selected Studies</b>
1. ER Questionnaire (ERQ)	4
2. ER task	3
3. UWIST Mood Adjective Checklist	1
4. Affective Schedule (PANAS)	1
5. ER Questionnaire (DERS)	1
6. Ruminative Response Scale (RSS);	1
7. ER task “similar to the tasks adopted in other classic studies” (Xui et al., 2018, p.3)	1
8. ER task (WNIC)	1
9. ER task (CRC)	1
10. ER task (ADC)	1
11. Cognitive ER Questionnaire (CERQ)	1
12. Explicit ER task	1

**4.6 Conclusion**

In the analysis of the 15 selected studies, attention was drawn to the PVO strategy for systematic exploratory reviews (Silva et al., 2017) by analysing the population (contextual factors), variables (the WM-ER dyad and stress), and the main outcomes of the trials. For the purpose of analysis, the researcher strictly adhered to the steps encompassing the methodology of systematic reviews as they pertain to the selection of studies following predefined eligibility criteria and quality assessment for the risk of bias. The implications of WM-T for WM and ER were considered and discussed in keeping with one of the main objectives of the research. Chapter 5 will further provide a discussion and the conclusion to the present study.

## **Chapter 5: Discussion and Conclusion**

### **5.1 Introduction**

In Chapter 4 the 15 studies were analysed and then integrated with the conceptual framework to provide clarity on the third aim of the study regarding WM, ER and stress being implicated in WM-T. The present study was navigated by three aims, namely, the relationship between WM and ER, stress as an influence in the WM-ER dyad, and the implications of the WM-ER dyad and stress for WM-T as an intervention strategy to facilitate functioning of ER. The final chapter provides a brief outline of the chapters in the present study, a discussion following the argument presented on the topic, a conclusion, limitations of the present study, and lastly, recommendations for future research.

### **5.2 Overview of the Chapters**

#### **5.2.1 Chapter 1: Introduction**

The introductory chapter gave a brief overview of key terms and provided the background of the research. The chapter justified the importance of the study, the objectives of the study, and clearly stated the aims of the research. The research question, paradigmatic lenses, a summary of the research methodology, and an outline of the structure of the study were also specified.

#### **5.2.2 Chapter 2: Literature Review**

The literature review provided the conceptual framework through a comprehensive collection of literature which was arranged in a logical and coherent fashion. The literature review commenced by introducing and defining WM and ER. The WM-ER dyad was then explored, touching upon the neurological basis of WM and ER. The influence of stress on the WM-ER dyad was discussed, as well as psychological affective states in relation to WM and ER. WM-T was explored within the realms of how WM-T has progressively developed over time, the various WM-T tools used by researchers, and the limitations of WM-T. Lastly, WM-T and eWM-T, for ER outcomes, were briefly discussed.

#### **5.2.3 Chapter 3: Research Methodology**

This chapter detailed the methodological decisions that were made for conducting the study. The characteristics and requirements of both a systematic and an exploratory review were critically compared, and it was explained how both types of reviews would be used to

conduct the semi-systematic study. The process of extracting studies was carried out with inclusion and exclusion criteria and followed systematic review protocols. A list of selected studies was categorised and tabulated, and the quality assessment of the eligible studies was conducted. The chapter concluded with the ethical considerations of the study.

#### **5.2.4 Chapter 4: Analysis and Results**

In this chapter, the analysis was conducted according to the PVO strategy for systematic exploratory reviews. The sample of selected studies was analysed to provide information on the population (contextual information), variables (the WM-ER dyad and stress), and the outcomes that were found in the studies. This chapter integrated the analysis with the conceptual framework and academic literature concerning the implications of WM-T.

#### **5.2.5 Chapter 5: Discussion and Conclusion**

This chapter provided a brief outline of the chapters in the present study, a discussion, the conclusion of findings, limitations of the present study, and lastly, recommendations for future research.

### **5.3 Discussion**

The discussion focuses on the three core aims of the study. The researcher found several discrepancies of WM-T to improve ER after closely examining the development of general WM-T over the past 19 years. First and foremost, there is still too much contradictory literature regarding the efficacy of WM-T to strengthen WM and if training effects are plausible. It is, therefore, difficult to assume that such a flawed and unreliable training intervention could have far-reaching effects on a complex system such as ER. There is evidence that WM-T for ER outcomes has been difficult due to implications identified in studies, such as the multifaceted relationships between the updating and attention orientation functions in WM, and ER (Xui et al., 2018).

Second, from the analysis of the population in the selected studies, the heterogeneity of characteristics, including gender, age, race, ethnicity, and socioeconomic status of participants can limit the external validity and the ability to generalise the results to the general population (Gravetter & Forzano, 2010). In particular, from the analysis of the age and gender of participants, an undergraduate female population heavily outweighed males and slightly older participants in training studies. According to Schmeichel et al. (2008), several theorists had suggested that low WM capacity had been underrepresented in college student samples. This proposal led to many prominent investigations of WM-T sampling students

from extremes of WM capacity distribution, including the study by Schmeichel et al. (2008). Yet, including studies with college students as participants weakens the validity of studies as the undergraduate shares with the laboratory rat the status of the most easily available and, therefore, most favoured participant in behavioural research (Gravetter & Forzano, 2010). Of the 15 studies, 11 had a  $M_{age}$  of between 18 and 26 years old. Of the 18-26 cohort, 91% were university or college graduate or undergraduate students over the proximate 27-44 cohort. Evidence is accumulating to suggest that many of the characteristics of college students limit the ability to generalise the results to other adults (Gravetter & Forzano, 2010). College students are likely to have a less formulated sense of self, a stronger tendency to comply with authority, less stable peer relationships, and higher intelligence than noncollege adults (Sears, 1986, as cited in Gravetter & Forzano, 2010). 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). Due to the limitation stemming from the fact that the vast majority of the selected studies just used university students, these studies do not accurately represent the emerging adult. There was not enough information regarding the university students to inform the researcher if they were working or had part-time jobs, were struggling financially, living at home or on campus, or had other life stressors that added to the role of being an emerging adult.

Third, through the quality assessment that the researcher conducted on the selected studies, there were problems concerning ethical considerations. 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 bias in the outcomes. Fifty-three percent of the studies failed to discuss if 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 the title stated ‘investigating the relationship between WM and ER in mothers’, thus limiting the construct validity of measurements in the study (Bemath et al., 2020). Ethical practices of issues around 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), and was the only study with such a small sample. However,

the small sample size was mentioned as a limitation in the study. Also, one study offered the university students extra credit on their scores for participating in the training, which could have indirectly induced a response bias. This reiterates the sentiment of neural reward circuitry previously mentioned as an implication of the WM-ER dyad in WM-T.

These discrepancies further complicate WM-T as a potential intervention strategy to facilitate ER functioning and should be considered in the implementation of future research directions.

## **5.4 Conclusion of Findings**

Research indicates that WM-T effects on ER connect with functionally distinct networks as the higher-thinking parts of the cortex (PFC and ACC) exhibit control over the reactive amygdala (via a top-down mechanism) (Wolf et al., 2018; Zhang et al., 2016; Deng et al., 2021). The ER network is separate from but adjacent to WM (Lee & Xue, 2018) and from a neuroscientific viewpoint, the “adjacency” of WM-ER neural networks settles the two apparently 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).

Moreover, the suggestion of training improvements implicating brain reward circuitry could be responsible for training gains found in WM-T for ER outcomes (Long et al., 2020). Due to reward-induced training effects in WM-T, expectations can incite the improvement of emotional experiences (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 as shown in the study investigating the Placebo effect of WM-T for ER outcomes by Long et al. (2020). Crocker et al. (2013) posit that cognition, emotion, and motivation are implemented by overlapping networks.

Furthermore, stress as a variable was underrepresented in the selected sample of studies. Although several studies recommended that stressful contexts be included in future training studies, only three of the studies included stress as a variable, training task, or scale. Researchers posit that stress experienced during training may influence training effectiveness (Raio et al., 2013).

Lastly, publication bias has been found in WM updating training studies suggesting that studies with smaller samples exhibiting large training effects were more likely to have been published, which could potentially overestimate the overall effect size (Pappa et al., 2020). This demonstrates the need for quality in 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 quality evidence.

### **5.5 Limitations of the Present Study**

The researcher noted the following limitations in the present study. The sample size of the published articles used in the systematic review was small and a larger sample size is needed for future research. The study sample also lacked stress as a variable and a more sophisticated search strategy is needed to include WM-T studies with stress as a variable. 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 obtaining all existing studies and gaining access to studies not provided by the University can become too costly for the researcher.

The researcher noted the limitations of the systematic review which include the propensity to research all available literature - with an ever-increasing amount of research available and the limited time available – rendering a fully-fledged systematic review practically unfeasible. Finding peer-reviewed journals in a wide range of databases can be costly and challenging for researchers who are non-academic (Mallet et al., 2012). Studies which are not well written or do not give details, demand from the researcher to ask the authors details of the missing information, which might be daunting and time-consuming for the researcher (Kitchenham, 2004). The other limitation in systematic reviews is that studies that yield negative results are unlikely to be published (Kitchenham, 2004).

The systematic review of studies set limiters on the database searches. The limiters included the age group of 18 to 60 years. The selected studies did not have a sample population that included children or adolescents under the age of 18 and did not include adults over the age of 60. This age limiter, therefore, prevents the findings to be applied to the general population. The language limiter was set to English, which eliminated studies from other countries, especially from China, who appear to be at the forefront of investigation into WM-T associated with ER and the mechanisms underlying WM and ER. One such article from Peng et al., (2019) was unable to be included in the present study due to the full article

only being available in Chinese. There may have been other studies that were missed in the database search due to limiting the language to English.

As a result of the PVO strategy being employed, there was limited consideration of methodology or data analysis in the analysis. The researcher included the methodological shortcomings found across the selected studies pertaining to the training tasks used to measure WM and ER. However, a more rigorous analysis is needed to pinpoint potential methodological issues affecting the studies.

Demographic characteristics such as gender and age were skewed and therefore limited the external validity and the ability of the current study to generalise the results (Gravetter & Forzano, 2010). In particular, the undergraduate female population far outweighed the older male population in the sample of studies.

## **5.6 Recommendations for Future Working Memory Training Studies**

The researcher encourages future research that includes emotional WM-T (eWM-T) in real-life, stressful situations and environments whereby ER can be a direct target for improvement. In addition, the various mechanisms of training, expectation, or other subjective variables and their interactions should be investigated in the future, instead of examining the mechanisms that underpin improvements in cognitive training (Long et al., 2020). Recommendations for more ethical standards and evidence of quality research seem plausible due to publication bias, researcher expectations, and the lack of standardised training tasks, training assessments and methodologies, found in the WM-T studies.

The following recommendations for future studies were obtained from review studies and meta-analyses, South African studies, a study that investigated the effects of WM-T on cognitive, affective, and biological responses to stress in MDD, and from the selected empirical WM-T studies used in the systematic review.

- **Assessments and Training Tasks**

There should be a higher level of standardisation across pre-and posttraining assessments (Morrison & Chein, 2011). Jopling et al. (2020) have suggested different training tasks be used for assessment and training (within a single study), due to suggestions that exposing a control group to pre-training tasks which are similar to training tasks used in the training, may improve WM ability (Jopling et al., 2020). Fraser and Cockcroft (2020) noted that the subjectivity of The Working Memory Rating Scale needs acknowledgment. The evaluation of WM-T games for portable devices, including more African content, are encouraged (Fraser & Cockcroft, 2020). Fraser and Cockcroft (2020) used Jungle Memory™

(2008) as a computerised WM intervention in their study as it supports Baddeley's (2000) multicomponent model and is in an adaptive game format. The inclusion of training tasks using the orientation function could improve ER in the future (Xui et al., 2018). One commonly used psychometric tool that could support the measurement aspect of ER is the Brunel Mood State Scale (BRUMS) which is used extensively internationally (Van Wijk & Martin, 2021). BRUMS is convenient for local use due to the availability of published South African norms and has good concurrent and criterion validity which has been reported internationally and locally (Van Wijk & Martin, 2021).

- Training for Neurological Populations

There is a dire need to establish valid training interventions for neurological samples in order for research findings to translate into clinical settings (Pappa et al., 2020).

- Training Groups

To eliminate confusing differences in findings, the active control groups should have experiences similar to that of the training group (Morrison & Chein, 2011). Barkus (2020) mentioned that WM-T for ER outcomes should be conducted across a variety of participants, from healthy through to clinical groups, as well as non-clinical associated with mental health disorders. Future studies also need to gauge the appropriate sample sizes for WM-T for optimising study design and procedures to maximise the possibility of having positive training effects (Barkus, 2020).

- Personalised Working Memory Training

There is potential for matching specific training programs to specific individuals in order to improve training gains (Morrison & Chein, 2011) and WM-T should be personalised to the particular requirements of participants (Fraser & Cockcroft, 2020). Therefore, future investigations for individual differences for WM-T are required (Barkus, 2020). Furthermore, behavioural statistics indicate the importance of personalising training to an individual's emotional context (Cohen & Ochsner, 2018).

- Technological Improvements and Training Costs

WM-T games for portable devices are encouraged (Fraser & Cockcroft, 2020). Relative costs and benefits of the training need consideration (Fraser & Cockcroft, 2020).

- Consideration of Socio-economic and Environmental Factors

It is required to assess the impact of WM and SR on the achievement of social skills by managing environmental factors, such as family demographics and socio-economic status

(Dučić et al., 2018). Bemath et al. (2020) disclosed that WM ability cannot be thought of as detached from the socio-ecological situation of the individual.

- The Holistic Approach to Cognition

Isolating different mechanisms of cognition offers a false sense of how it works in real life and, therefore, a more holistic approach would better serve research into cognition (Bemath et al., 2020).

## **5.7 Conclusion of Research Study**

Clarification of the relationship between WM and ER - touching upon the neural basis of the WM-ER dyad – and its implication for WM-T, steered the present study. The study was governed by three aims to investigate the WM-ER dyad and the influence of stress on the WM-ER dyad which are implicated in WM-T to facilitate ER functioning. The semi-systematic review enabled the researcher to map the field of cognition and emotion, combine the state of knowledge, provide a historical overview or timeline of WM-T, and make recommendations for further research. The systematic exploratory review investigated academic literature and a sample of empirical studies to fill the gaps that exist in our knowledge about the relationship between WM and ER and their implications for WM-T as an interventions strategy to improve ER. The literature review encompassed definitions and theories of WM and ER and provided the conceptual framework for the neurological underpinnings of WM and ER, as well as the role of stress in the WM-ER dyad. A developmental timeline for WM-T was made to keep abreast of WM-T research and encompass the developments and trends in WM-T intervention studies. WM-T has constantly adapted to what training transfer effects require and due to this review's semi-systematic and flexible nature, the researcher was able to reposition the study with the versatile nature of WM-T during the investigation. The studies that were selected for the systematic review of articles were analysed and the results were discussed by combining information from the analysis of the selected studies with the theoretical and conceptual framework. The gaps in literature exist around the mechanisms of WM and ER and how that implicates WM-T for ER outcomes. Stress, depending on its severity and duration, has a significant impact on the WM-ER dyad and has been under-investigated. The present study presents findings that has the potential to change the direction of the investigation into WM-T for ER outcomes.

The study recommended how WM-T can be improved in the future, including recommendations for the South African context. Recommendations for future WM-T research

directions could lead to further possible insights into WM-T to improve ER for the psychological well-being and professional success of individuals.

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## **Appendices**

**Appendix A: List of definitions of abbreviations used**

**Appendix B: Search History and Results**

**Appendix C: Data Extraction Form**

**Appendix D: Adapted CASP Tool for Quantitative Studies**

**Appendix E: Studies Sampled for Review/Coding**

## Appendix A: List of Definitions of Abbreviations Used

Abbreviation	Definition
<b>ACC</b> (Anterior Cingulate Cortex)	A region in the brain critically supporting mood regulation (Schweizer et al., 2013) and plays a role in emotional processing, attention, and WM (Greenberg, 2006).
<b>ADHD</b> (Attention Deficit Hyperactivity Disorder)	<i>Attention deficit hyperactivity disorder</i> (ADHD) is characterized by inattention, impulsivity, and hyperactivity (American Psychiatric Association, 1994, as cited in Klingberg, 2002).
<b>BD</b> (Bipolar Disorder)	<i>Bipolar disorder</i> (BD) entails a cyclical nature of fluctuating between extreme moods of either mania or hypomania, and depression (Zhang et al., 2016).
<b>CE</b> (Central Executive)	The CE controls the visuo-spatial sketch pad and phonological loop as these two neural loops store information for a short while until the information is forgotten as new information arrives (Baddeley, 2012). The CE also monitors and coordinates the visuo-spatial sketchpad and phonological loop whilst retrieving information stored in LTM (McLeod, 2012).
<b>CTM</b> (Computerised Training Methods)	Numerous commercial, computer-based, WM-T programmes have been developed, such as <i>CogMed</i> which is accessible in 30 countries and is generally used in schools and clinics (Melby-Lervåg & Hulme, 2013). Other WM-T programmes include <i>Jungle Memory</i> and <i>Cognifit</i> (Melby-Lervåg & Hulme, 2013; Fraser & Cockcroft, 2020).
<b>DLPFC</b> (Dorsolateral Prefrontal Cortex)	The DLPFC is a region in the brain associated with cognitive control and inhibition of emotional stimulation (Greenberg, 2006).
<b>ER</b> (Emotion Regulation)	<i>Emotion regulation</i> (ER) is a sub-component of <i>self-regulation</i> (SR) (Schmeichel et al., 2008) and is essential to psychological well-being and attempts to improve experience, expression, or the duration of an emotional reaction (Schmeichel et al., 2008).
<b>eWM-T</b> (Emotional Working Memory Training)	In this study, eWM-T includes the updating function in WM during WM-T. The updating function is the addition of emotional stimuli into WM.
<b>fMRI</b> (Functional Magnetic Resonance Imaging)	<i>Functional magnetic resonance imaging</i> (fMRI) studies have enabled researchers to investigate the different parts of the brain responsible for forming memories.
<b>GAD</b> (Generalised Anxiety Disorder)	The most widespread psychological or neurodevelopmental disorder (Ritchie & Roser, 2018).
<b>LTM</b> (Long-Term Memory)	Consolidated information and memories can be retrieved from the <i>long-term memory</i> (LTM).
<b>MDD</b> (Major Depressive)	Depression is characterised by difficulty eliminating negative information from WM (Jopling et al., 2020).

Disorder)	
<b>NA</b> (Noradrenaline)	NA is an important neuromodulator of the central nervous system (Kuo et al., 2021). The NA system is linked to increased brain processing of information, and focusing attention on relevant information by ignoring irrelevant information (Viljoen & Panzer, 2007).
<b>PFC</b> (Prefrontal Cortex)	The PFC is an area in the brain that maintains attention that supports WM and other complex mental processes (Barkus, 2020).
<b>PTSD</b> (Posttraumatic Stress Disorder)	In patients with PTSD, flashbacks occur when the amygdala is overstimulated and the PFC is briefly disabled (Fishbane, 2007).
<b>SR</b> (Self-Regulation)	The monitoring of thought, feeling, or behaviour; motivation towards effortfully matching desired standards with current states; and the ability to reduce the discrepancy between the desired standards and current states (Hofmann et al., 2012). Moreover, SR includes the ability to adapt behaviour and is a process of executive functioning (Hofmann et al., 2012; Dučić et al., 2018).
<b>WM</b> (Working Memory)	WM is part of our cognition that assists us to not only to temporarily retain information but also to manipulate incoming information for the purpose of problem-solving and other mentally challenging activities in our everyday lives (Baddeley, 1992).
<b>WM-T</b> (Working Memory Training)	WM-T reveals a myriad of different tools and training tasks that have been utilised in an attempt to improve WM. These are listed in Section 2.10.3.

## Appendix B: Search History and Results

Search ID#	Search Terms	Advanced Search Options	Database(s)	Results
S1	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Scholarly Journals, Peer-reviewed Articles, Language: English, Search modes: Boolean/Phrase	ProQuest Central	189
S2	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Review Articles, Year of Publication: 2002-2021, Search modes: Boolean/Phrase	ScienceDirect	20
S3	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Year of Publication: 2002-2021, Search modes: Boolean/Phrase	Sage	16
S4	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Linked Full Text; Publication Year: 2002-2021; Peer Reviewed; Publication Type: Peer Reviewed Journal, Language: English; Age Groups: Adulthood (18 years & older); Document Type: Journal Article; Methodology: Empirical Study; Exclude Dissertations, Search modes: Boolean/Phrase	PsycInfo	6
S5	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Full Text; Year of Publication: 2002-2021; Scholarly (Peer Reviewed) Journals; Exclude Book Reviews; Exclude Non-Article Content; Age Groups: Adulthood (18 years & older); Methodology: Empirical Study, Search modes: Boolean/Phrase	PsycArticles	1

Search ID#	Search Terms	Advanced Search Options	Database(s)	Results
S6	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: PDF Full Text; Year of Publication: 2002-2021; Scholarly (Peer Reviewed) Journals; Language: English, Search modes: Boolean/Phrase	Academic Search Complete	2
S10	("Working memory training" OR "emotional working memory training") AND "Emotion regulation"	Limiters applied: Date of Publication: 2002-2021, Pretoria library(WorldCat, Ebsco@UP, Merensky Library – FullText@UP, ProQuest Fulltext) Search modes: Boolean/Phrase,	Google Scholar	1680
S11	"Working memory training" AND "Emotion regulation" AND Stress	Limiters applied: Year of Publication: 2002-2021; Document Type: Article; Open access; University of Pretoria Libraries; Search modes: Boolean/Phrase	Academic Search Complete WorldCat	2
S12	("Working memory training" OR "emotional working memory training") AND "Emotion regulation" AND Stress	Limiters applied: Peer-reviewed, Exclude Wire Feeds; Date: From 2002 to 2021; Source Type: Scholarly Journals; Document Type: Article; Language: English	ProQuest Central	134

## Appendix C: Data Extraction Form

The data extraction form was coordinated chronologically so as to assist in the systematic process of literature reviewing and to allow the researcher to make changes due to the development of literature over time.

	Reference	Data Source	Database	Included/ Excluded	Comment
1.	Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A. (2008).	Working memory capacity and the self-regulation of emotional expression and experience.	PsycArticles	Included	(Attained through reference) USA study
2.	Wingo, A. P., Fani, N., Bradley, B., & Ressler, K. J. (2010).	Psychological resilience and neurocognitive performance in a traumatised community sample.	Academic Search Complete	Excluded	(Attained through reference) Did not have a working memory intervention
3.	Schmeichel, B. J., & Demaree, H. A. (2010).	Working memory capacity and spontaneous emotion regulation: High capacity Predicts self-enhancement in response to negative feedback.	PsycArticles	Included	(Attained through reference) USA study
4.	Schweizer, S., Hampshire, A., & Dalgleish, T. (2011).	Extending Brain-Training to the Affective Domain: Increasing Cognitive and Affective Executive Control through Emotional Working Memory Training.	PubMed Central	Excluded	The study did not make a direct reference to ER.
5.	Pe, M. L., Koval, P., & Kuppens, P. (2012).	Executive well-being: Updating of positive stimuli in working memory is associated with subjective well-being.	ScienceDirect Journals	Included	Belgium study
6.	Crocker, L. D., Heller, W., Warren, S. L., O'Hare, A. J., Infantolino, Z. P., & Miller, G. A. (2013).	Relationships among cognition, emotion, and motivation: Implications for intervention and neuroplasticity in psychopathology	ProQuest Central	Excluded	Did not report empirical data (Review)
7.	Engen, H. & Kanske, P. (2013).	How working memory training improves emotion regulation: Neural efficiency, effort, and transfer effects.	PubMed Central	Excluded	Did not report empirical data
8.	Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., & Dalgleish, T. (2013).	Training the emotional brain: Improving affective control through emotional working memory training.	PubMed Central	Included	UK study
9.	Krause-Utz, A., Elzinga, B. M., Oei, N. Y. L., Paret, C., Niedtfeld, I.,	Amygdala and Dorsal Anterior Cingulate Connectivity during an Emotional Working Memory Task in Borderline	ProQuest Central	Excluded	No reference to ER in the study

	Reference	Data Source	Database	Included/ Excluded	Comment
	Spinhoven, P., Bohus, M., & Schmahl, C. (2014)	Personality Disorder Patients with Interpersonal Trauma History			
10.	Dubert, C. J., Schumacher, A. M., Locker, L., Gutierrez, A. P., & Barnes, V. A. (2016).	Mindfulness and emotion regulation among nursing students: Investigating the mediation effect of working memory capacity.	Springer eJournals	Included	USA study
11.	Evans, L. D., Kouros, C. D., Samanez-Larkin, S., & Garber, J. (2016).	Concurrent and short-term prospective relations among neurocognitive functioning, coping, and depressive symptoms in youth.	Academic Search Complete	Excluded	(Attained through reference) Did not meet inclusion criteria: Ages 9 to 15 ( <i>M</i> age = 12.36)
12	Rutherford, H. J. V., Booth, C. R., Crowley, M. J., & Mayes, L.C. (2016).	Investigating the relationship between working memory and emotion regulation in mothers.	Taylor & Francis eJournals UP	Included	USA study
13.	Xiu, L., Zhou, R., & Jiang, Y. (2016).	Working memory training improves emotion regulation ability: Evidence from HRV.	ScienceDirect Journals	Included	Chinese study
14.	Hitchcock, C., & Westwell, M. S. (2017).	A cluster-randomized, controlled trial of the impact of Cogmed working memory training on both academic performance and regulation of social, emotional, and behavioural challenges.	Wiley Online Library Database	Excluded	Did not meet inclusion criteria: Age: Children
15.	Cohen, N., & Ochsner, K. N. (2018).	From surviving to thriving in the face of threats: the emerging science of emotion regulation training	ScienceDirect	Excluded	Did not report empirical data
16.	Dučić, B., Gligorović, M., & Kaljača, S. (2018).	Relation between working memory and self-regulation capacities and the level of social skills acquisition in people with moderate intellectual disability.	Academic Search Complete	Excluded	Did not meet inclusion criteria: Ages 14 to 21
17.	Luke, C., Redekop, F., & Jones, L. K. (2018).	Addiction, stress, and relational disorder: A neuro-informed approach to intervention.	ProQuest Central	Excluded	Did not report empirical data
18.	Tien-Wen, L., & x Shao-Wei Xue. (2018).	Does emotion regulation engage the same neural circuit as working memory? A meta-analytical comparison between cognitive reappraisal of negative emotion and 2-back working memory task	ProQuest Central	Excluded	Did not report empirical data (Meta-Analytical Study)
19.	Xui, L., Wu,	Working memory training	ProQuest Central	Included	Chinese study

	Reference	Data Source	Database	Included/ Excluded	Comment
	J., Chang, L., & Zhou, R. (2018).	improves emotion regulation ability.			
20.	Yoon, K. L., LeMoult, J., Hamedani, A., & McCabe, R. (2018).	Working memory capacity and spontaneous emotion regulation in generalised anxiety disorder.	Academic Search Complete	Included	Canadian study
21.	Peckham, A. D., Johnson, S. L., & Swerdlow, B. A. (2019).	Working memory interacts with emotion regulation to predict symptoms of mania.	ScienceDirect Journals	Included	USA study
22.	Peng, W., Luo, W., & Zhou, R. (2019).	HRV evidence for the improvement of emotion regulation in university students with depression tendency by working memory training.	PsycInfo	Excluded	Unable to attain article full article in English (article only available in Chinese)
23.	Wang, X., Pan, D., Li, X., & 12th International Conference on Brain Informatics, BI 2019 12th 2019 12 13 - 2019 12 15. (2019).	The neural mechanism of working memory training improving emotion regulation.	SpringerLink	Included	Chinese study
24.	Barkus. (2020).	Effects of working memory training on emotional regulation: Transdiagnostic review.	Wiley Online Library Database	Excluded	Did not report empirical data (Transdiagnostic Review)
25.	Bemath, N., Cockcroft, K., & Theron, L. (2020).	Working memory and psychological resilience in South African emerging adults.	Sage Journals	Included	South African study
26.	Groves, N. B., Kofler, M. J., Wells, E. L., Day, T. N., & Chan, E. S. M. (2020)	Examination of Relations Among Working Memory, ADHD Symptoms, and Emotion Regulation	ProQuest Central	Excluded	Did not meet inclusion criteria: Children ages 8-13 years
27.	Long, Q., Hu, N., Li, H., Zang, Y., Yuan, J., & Chen. A. (2020).	Suggestion of cognitive enhancement improves emotion regulation.	PsycArticles	Included (Exception made for exclusion criteria: ages 17 to 24)	Chinese study
28.	Pan, D. N., Hoid, D., Wang, X. B., Jia, Z., & Li, X. (2020).	When expanding training from working memory to emotional working memory: not only improving explicit emotion regulation but also implicit negative control for	ProQuest Central	Included	Chinese study

	Reference	Data Source	Database	Included/ Excluded	Comment
		anxious individuals.			
29.	Deng, Y., Hou, L., Chen, X., & Zhou, R. (2021).	Working memory training improves emotion regulation in drug abstainers: evidence from frontal alpha asymmetry.	ScienceDirect Journals	Included	Chinese study

## Appendix D: Adapted CASP Tool for Quantitative Studies

The researcher used the adapted CASP (Critical Appraisal Skills Programme) tool for quantitative articles from Laher & Hassem (2020) to assess the quality of the 15 selected studies included in the systematic review.

<b>1. Was there a clear statement of the aims of the research?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: What was the goal of the research? Why it was thought important? Its relevance	
<b>2. Is a quantitative methodology appropriate?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the research seeks to examine a relationship between variables or comparison of groups. Is quantitative research the right methodology for addressing the research goal?	
Is it worth continuing?	
<b>Detailed questions:</b>	
<b>3. Was the research design appropriate to address the aims of the research?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the researcher has justified the research design (e.g., have they discussed how they decided which method to use)?	
<b>4. Was the recruitment strategy appropriate to the aims of the research? (Assess selection bias)</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the researcher has explained how the participants were selected, are the individuals selected to participate in this study likely to be representative of the target population? If there are any discussions around recruitment (e.g., why some people chose not to take part)	
<b>5. Was the data collected in a way that addressed the research issue?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the setting for data collection was justified. If it is clear how data were collected. Were data collection tools shown to be valid? Were data collection tools shown to be reliable? If methods were modified during the study. If so, has the researcher explained how and why?	
<b>6. Were the research methods justified by the researcher?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the researcher has justified the methods chosen. If the researcher has made the methods explicit.	
<b>7. Have ethical issues been taken into consideration?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If there are sufficient details of how the research was explained to participants for the reader to assess whether ethical standards were maintained. If the researcher has discussed issues raised by the study (e.g., issues around informed consent, anonymity, and confidentiality or how they have handled the effects of the study on the participants during and after the study). If approval has been sought from the ethics committee	
<b>8. Was the correct statistical technique used to analyse the data?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: Was descriptive data provided? Was the sample size large enough for the statistical technique carried out? Were basic assumptions of the statistical test utilised met? Were both significant and insignificant results reported? Did the statistical technique used effectively answer the research question?	
<b>9. Was the data analysis sufficiently rigorous?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If there is an in-depth description of the analysis process. Were the statistical methods appropriate for the study design? If sufficient data are presented to support the findings? To what extent contradictory data are taken into account? Were potential sources of bias discussed?	
<b>10. Were psychometric properties discussed?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: Were reliability and validity of the instruments used discussed or analysed	
<b>11. Is there a clear statement of findings?</b>	<input type="checkbox"/> Yes <input type="checkbox"/> Can't tell <input type="checkbox"/> No
Consider: If the findings are explicit. If there is adequate discussion of the evidence both for and against the researchers' arguments. If the findings are discussed in relation to the original research question.	

## Appendix E: Studies Sampled for Review/Coding

The following three tables are categorised as stated in Chapter 3 and the studies are coordinated chronologically within each table.

### WM-T Tools Utilised in the Investigation of the Relationship Between Working Memory and Emotion Regulation

No.	Authors	Year	Title	Publication
1.	Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A	2008	Working memory capacity and the self-regulation of emotional expression and experience.	Journal of Personality and Social Psychology.
2.	Schmeichel, B. J., & Demaree, H. A	2010	Working memory capacity and spontaneous emotion regulation: High capacity Predicts self-enhancement in response to negative feedback.	Emotion.
3.	Dubert, C. J., Schumacher, A. M., Locker, L., Gutierrez, A. P., & Barnes, V. A.	2016	Mindfulness and emotion regulation among nursing students: Investigating the mediation effect of working memory capacity.	Mindfulness.
4.	Rutherford, H. J. V., Booth, C. R., Crowley, M. J., & Mayes, L.C	2016	Investigating the relationship between working memory and emotion regulation in mothers.	Journal of Cognitive Psychology.
5.	Yoon, K. L., LeMoult, J., Hamedani, A., & McCabe, R.	2018	Working memory capacity and spontaneous emotion regulation in generalised anxiety disorder.	Cognition and Emotion.
6.	Peckham, A. D., Johnson, S. L., & Swerdlow, B. A.	2019	Working memory interacts with emotion regulation to predict symptoms of mania.	Psychiatry Research.
7.	Bemath, N., Cockcroft, K., & Theron, L.	2020	Working memory and psychological resilience in South African emerging adults.	Psychology of Learning and Motivation.

### Working Memory Training Utilised for Emotion Regulation Training Gains

No.	Authors	Year	Title	Publication
8.	Xui, L., Wu, J., Chang, L., & Zhou, R.	2018	Working memory training improves emotion regulation ability.	Scientific Reports.
9.	Wang, X., Pan, D., Li, X., & 12th International Conference on Brain Informatics, BI 2019 12th 2019 12 13 - 2019 12 15.	2019	The neural mechanism of working memory training improving emotion regulation.	Lecture Notes in Computer Science, 11976.
10.	Long, Q., Hu, N., Li, H., Zang, Y., Yuan, J., & Chen. A.	2020	Suggestion of cognitive enhancement improves emotion regulation.	Emotion.
11.	Deng, Y., Hou, L., Chen, X., & Zhou, R.	2021	Working memory training improves emotion regulation in drug abstainers: evidence from frontal alpha asymmetry.	Neuroscience Letters.

### Emotional Working Memory Training Utilised for Emotion Regulation Training Gains

No.	Authors	Year	Title	Publication
12.	Pe, M. L., Koval, P., & Kuppens, P.	2012	Executive well-being: Updating of positive stimuli in working memory is associated with subjective well-being.	Cognition.
13.	Schweizer, S., Grahn, J., Hampshire, A., Mobbs, D., & Dalgleish, T.	2013	Training the emotional brain: Improving affective control through emotional working memory training.	The Journal of Neuroscience.
14.	Xiu, L., Zhou, R., & Jiang, Y.	2016	Working memory training improves emotion regulation ability: Evidence from HRV.	Physiology & Behavior.
15.	Pan, D. N., Hoid, D., Wang, X. B., Jia, Z., & Li, X.	2020	When expanding training from working memory to emotional working memory: not only improving explicit emotion regulation but also implicit negative control for anxious individuals.	Psychological Medicine.