



The Impact of Emotional Working Memory on Emotional Regulation and Relevant Interventions

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Abstract. Working memory is a cognitive system that temporarily stores a limited information capacity due to competition of cognitive activity for use during ongoing processing. Working memory is domain-general and linked to various cognitive activities. Working memory training has been developed to help people boost their working memory capacity. Emotion regulation is a cognitive process that entails an individual's deliberate efforts to manage their emotional states from the impulsive flow of emotional responses. As research regarding the relationship between working memory and emotion regulation is scarce, this review investigated and demonstrated that there is a relationship between working memory capacity and emotion regulation. Working memory capacity's relationship with emotion regulation was also explored in clinical populations. Subsequently, this review also explored whether working memory training affected emotion regulation and clinical symptoms in typically developing and clinical populations. These findings have limitations as the emotion regulation measurements used in previous studies were mainly subjective and did not objectively reflect emotional regulation in real life. Plus, previous studies did not evaluate working memory training's long-term effectiveness. This paper showed the relationship between working memory and emotion regulation. Subsequently, this paper also evaluated the effectiveness of working memory training. This paper can provide guidance for future intervention studies and practices that target working memory and emotional regulation.

Keywords: Emotional Working Memory · Emotion Regulation · Working Memory Training · Post-Traumatic Stress Disorder

1 Introduction

Short-term memory is described as the simple maintenance, or without alteration, of information in memory over a brief time period. Working memory, on the other hand, is the manipulation of stored information [1]. For example, short-term memory might be tested if someone heard a list of items and simply repeated it. However, if they rearrange the list of items, it is a test of working memory. Working memory is more precisely defined as a cognitive system that temporarily stores a limited capacity of information due to competition of cognitive activity for use during ongoing processing [1].

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Accordingly, working memory capacity is the limit of an individual's ability to retain relevant information amid other distractions due to the competition of limited cognitive resources [2]. Previous research indicated that working memory capacity is domain-general and linked to various cognitive activities. Crucially, previous research has indicated that compared to individuals with low working memory capacity, individuals with high working memory capacity excel better in activities that require them to ignore distracting information. For example, in the Stroop task, participants are asked to state the word's ink color while ignoring its real meaning (i.e., saying "blue" when the word "green" is shown in blue ink). Results indicate that it was easier to ignore the automatic response to the color words presented for individuals with higher working memory capacity. Hence, it is essential to understand working memory, as it can have critical implications for cognitive development and processing. Plus, working memory deficit is a viable explanation for the cause of various developmental cognitive disorders. Emotional regulation is a higher-level cognitive ability that entails an individual's deliberate efforts to regulate and override their emotional states from the natural flow of emotional responses [3]. In a general view, emotional regulation is a system in which individuals manage and control all their emotionally charged states.

Working memory training is critical to understand, as it can improve working memory capacity. As a result, achieving a better understanding of working memory training can be utilized to develop various training treatments and interventions for a multitude of cognitive disorders. Likewise, it is critical to understand emotional regulation as chronic emotional regulation deficits negatively affect physical well-being and contribute to all major forms of psychopathology and physical well-being. Moreover, since emotion regulation and emotional working memory are both belong to the social cognition area, it is crucial to investigate the working memory and its relationship with emotion regulation, especially as research explored this relationship is scarce. Subsequently, it is also essential to investigate working memory training and its effectiveness on emotion regulation.

Existing research examined working memory and its relationship to various cognitive activities, such as language processing, the control of visual attention, and the ability to disregard the non-relevant information in the dichotic listening task. Findings from existing research agree that working memory has a significant role in goal-relevant processing amid the presence of irrelevant information and distractions [2]. Due to this nature, current trends in research primarily focus on working memory training's effectiveness in improving working memory by utilizing visual, verbal, auditory, and cross-modal memory tasks. In addition, though working memory is seen as domain-general, existing research supports that working memory training only produces narrow gains on functions that have been trained. As a result, current trends focus on developing more effective working memory training programs by targeting and training specific cognitive tasks or developing better training methods that can show better generalization and far-transfer effects.

In terms of emotional regulation research, current trends focus on categorizing different emotion regulation strategies that specify the system of how people manage unwanted emotions and how they implement emotion regulation strategies. Current theories classify three different strategies: need-oriented emotion regulation, goal-oriented emotion

regulation, and person-oriented emotion regulation. In a broad sense, need-oriented emotion regulation strategies focus on the need to experience hedonically rewarding states, consisting of high levels of positive emotions and low levels of negative emotions. Goals, norms, or tasks are essential components for goal-oriented emotion regulation. Goal-oriented emotion regulation promotes or inhibits different emotional states to achieve a specific goal. Whereas need-oriented and goal-oriented emotional regulation focus on aspects of emotional function, person-oriented emotion regulation focuses on the holistic functioning of the whole body.

However, limited research has been done investigating the relationship between working memory and emotion regulation. More importantly, previous research investigating working memory training involving emotional regulation and how it can be a valuable intervention treatment for those suffering from various mental disorders is even more scarce. Therefore, this review aims to better understand working memory and its relationship with emotion regulation and various mental disorders involving emotional dysregulation. Subsequently, this review then aims to examine studies investigating emotional working memory training's effectiveness to better understand how it can be developed as an intervention treatment for clinical populations. Finally, this review can provide guidance to future intervention studies for populations with working memory and emotional regulation deficits.

2 Typical and Atypical Emotional Working Memory and Emotion Regulation

2.1 The Effects of Emotional Stimuli on Working Memory

Emotional stimuli are significant as they elicit an emotional response from and processes within humans, and humans frequently encounter emotional stimuli. As a result, emotional stimuli can be a distractor in working memory and influence working memory capacity. For example, suppose a student with high working memory capacity is experiencing emotional distress from family. In that case, it might lead to a decrease in concentration and cognitive performance during a math test, which requires working memory. Therefore, it is essential to understand emotion regulation as it is a crucial element of well-being, and the superior ability to regulate emotions better is likely advantageous in a variety of circumstances. For example, the inferior ability to disguise one's excitement when holding a winning deck might result in other players knowing, possibly causing the player to win only a small pot. Thus, since regulating emotions is a complex cognitive process, it is likely that working memory capacity has a relationship with emotion regulation.

Through four studies, Schmeichel et al. investigated working memory capacity and its relationship with self-regulation of emotions [4]. The first two studies explored the working memory capacity's relationship with self-regulation of negative and positive emotional expression in undergraduates (18–23 years) using a set of questionnaires, a working memory capacity test, and a stimuli video. They found that higher working memory capacity participants significantly expressed fewer emotions after a stimuli video clip (either disturbing or humorous) than those with lower working memory capacity. The latter two studies explored whether working memory capacity influences the effectiveness

of adopting neutral appraisals of emotional stimuli in undergraduates (18–59 years), and the participants completed questionnaires, a working memory capacity test, and a stimuli video. The results demonstrated that those with higher working memory capacity significantly experienced fewer emotions in response to an emotionally charged video when adopting the emotion regulation strategy of neutral appraisals. Therefore, Schmeichel et al. suggest that individuals with higher working memory capacity are more capable of emotion regulation.

In addition, internal emotional states, such as internal anxious states, can similarly affect emotional working capacity. For example, if a student is highly anxious, it might cause them to underperform compared to their average level. Shi et al. assessed whether highly test anxious (i.e., where the formal evaluation of performance causes anxiety of excessive fear and worry) individuals under test-related conditions would have impaired emotional working memory capacity (i.e., the same concept as working memory capacity but with emotionally charged distractions) compared to lowly test anxious persons [5]. The study was assessed using a modified reading span (RS) task, which had a test-related condition (i.e., sentences linked to dysfunctional beliefs about tests) and a valence-neutral condition (i.e., sentences related to emotionally neutral facts about the world) in undergraduates (mean age = 19.77). The findings showed that highly test anxious participants performed worse in the test-related condition than in the valence-neutral condition. In addition, the results also indicated that there was no difference in the valence-neutral condition in highly and lowly test anxious individuals. Therefore, this study demonstrates that in the test-related condition, impaired emotional working memory capacity might be a feature of and contribute to test anxiety.

2.2 The Atypical Emotional Working Memory

From the above studies, it is evident that there is a relationship between working memory capacity and emotion regulation in typically developing populations. In clinical populations, emotion regulation deficits are likely related to deficiencies in working memory capacity. Significant symptoms of depression include a pervasive feeling of sadness and hopelessness. Likewise, typical symptoms of posttraumatic stress disorder (PTSD) include constant negative thoughts and re-experiencing traumatic events in forms such as repetitive and distressing images or sensations, flashbacks, or nightmares. These symptoms are likely contributed by emotion dysregulation, or in other words, difficulties with emotion regulation. Accordingly, working memory capacity impairments might be a factor in difficulties with emotion regulation, and the two clinical groups described below demonstrate abnormal emotional working memory capacity. Li et al. investigated whether there are differences in working memory ability between patients with major depressive disorder (MDD) and human controls. They also explored if there was a mood-congruent effect (i.e., the idea that it is easier to remember emotional information that matches with the current emotional state) in patients with MDD [6]. The study used an improved Sternberg working memory paradigm which allowed Li and colleagues to assess spatial and object working memory in a group of patients with MDD (18–60 years) and a group of matched human controls. In the improved Sternberg paradigm, emotional pictures were used instead of letters or numbers to detect non-spatial working memory. A picture position was also added to detect spatial working memory. This

means that the trial consisted of four pictures in each of the four corners of the screen, followed by a picture in a corner. Finally, the participants needed to identify as fast and accurately as possible if the image and its position appeared and matched the previous group of pictures. The results demonstrated a significantly lower accuracy in identifying picture positions and significantly longer response times in the MDD group than human controls. Hence, this study suggests that patients with MDD have emotional working memory impairments.

Updating is an essential component for working memory to function. In typically developing populations, working memory is frequently updated. For example, suppose an individual goes through a bad situation like getting fired and proceeds to do something positive like watching TV. In that case, their working memory will update, their emotions will update, and they will feel more positive emotions. However, in clinical populations like those with PTSD, it is more difficult to update their working memory and emotions. For example, if an individual encounters a bad situation, they will still think about it and obsess over that emotion even if they do something positive like watching TV. Therefore, it is essential to understand working memory in individuals with PTSD. Schweizer and Dalgleish assessed the emotional working memory capacity of participants with a history of PTSD and trauma-exposed controls with no history of PTSD [7]. The participants (17–65) were allocated into two groups. One group satisfied the clinical diagnosis of PTSD anytime in their lifetime (could presently have PTSD or have had PTSD). The latter group (control group) comprised those exposed to similar traumatic events but didn't meet the full criteria for PTSD. In addition, the participants completed an emotional working memory capacity task, which was an improved version of the traditional RS task. Participants had to memorize lists of emotionally neutral words in a short period of time while concurrently processing phrases depicting trauma-related thoughts relative to neutral control sentences. The significant results indicated that relative to performance with neutral phrases, participants who met the diagnosis of PTSD performed worse on the emotional working memory capacity task than the trauma-exposed control participants. These results demonstrate that those who have struggled with PTSD at any point in their lifetime may suffer from more significant emotional working memory capacity impairments than those who have not had PTSD. Overall, the two studies on clinical groups demonstrate emotional working memory capacity impairments, which might be a factor in emotion dysregulation.

3 The Effects of Emotional Working Memory Training

3.1 Emotional Working Memory Training and Emotional Regulation

Adolescents are a unique period in life as they usually have difficulties with emotion regulation, so it is essential to understand their emotional working memory capacity and whether increasing their emotional working memory capacity can contribute to better emotion regulation. Leone de Voogd and colleagues investigated emotional working memory training's impact on working memory capacity, the effect on depression and anxiety symptoms, and emotional functioning in a random sample of adolescents (11–18 years) [8]. The participants were randomly allocated to an active or placebo training condition. Participants were shown a fixation cross in both training conditions in both

groups, followed by a sequence of green and blue squares in a 4×4 matrix checkerboard pattern. Then a random sequence of squares lit up, and participants had to repeat the sequence by clicking all the green squares in the correct order then all blue squares in the correct sequence it was displayed. A negative emotional face was randomly placed on one of the lit squares as the emotional component. The training was adaptive based on active emotional working memory training performance. This means that the sequence length would decrease or increase based on performance. Whereas, in the placebo training group, training was non-adaptive – meaning that the length of the trial remained the same regardless of performance. The participants' working memory was assessed with a computerized task before and after the four weeks of training. Emotional functioning was assessed before and after training, as well as three, six, and twelve months after training. The results demonstrate that both the placebo and active emotional working memory training groups significantly increased their working memory capacity. Though active emotional training did not lead to a more considerable increase in working memory capacity than the placebo training, there was a trend-level increase in self-esteem. Overall, the findings indicate that both groups showed overall gains in working memory capacity and emotional functioning.

From the above discussions, it is evident that emotional working memory capacity has a relationship with anxiety. Accordingly, if these two factors are really related, then an increase in emotional working memory capacity from training should help individuals regulate anxiety more effectively. Veloso and Ty evaluated if participants (18–40 years) who underwent emotional working memory training would have lower trait anxiety (i.e., trait anxiety is the tendency to feel anxious in many different situations) post-training [9]. An experimental group completed a 20-day computerized emotional working memory training program that aims to increase working memory capacity by utilizing emotional stimuli in the training. On the other hand, the control group was simply instructed to practice healthy habits for the next 20 days. Before and after the 20 days, all participants were given questionnaires to measure their emotion regulation and trait anxiety. In addition, the experimental group also completed a working memory capacity test. The findings indicated that, compared to controls, participants who completed the emotional working memory training had significantly lower trait anxiety after training. Furthermore, mediation analysis suggested that gains in working memory training and reduced anxiety were significantly related. Therefore, these results indicate that emotional working memory training can increase working memory capacity and reduce levels of trait anxiety.

Consistent with the above study, emotional working memory training can also help reduce people's test anxiety. Minihan et al. assessed whether affective working memory training could minimize test anxiety and cognitive and emotional impairments in undergraduates (19–22 years) with test anxiety symptoms [10]. All participants completed questionnaires and tasks during the pre and post-training phases to assess their text anxiety, emotion regulation, cognitive control, and working memory. In addition, participants were divided into the emotional working memory training group, the neutral working memory training group, and the control group. The emotional working memory training comprised a dual n-back task with emotional stimuli. Neutral working memory training was identical to emotional working memory training, except the stimuli were neutral,

and the control group had no training. The dual n-back test involves the simultaneous serial presentation of visual and audio stimuli. Participants were asked to assess whether either stimuli matched the stimuli presented n-trials back and where the visual stimuli were located. The results indicated that both the emotional and neutral working memory training group demonstrated enhanced cognitive and emotional performance after training relative to the control group. Furthermore, the results indicated that the emotional working memory training group had significantly reduced test anxiety symptoms and improved emotion regulation relative to the neutral group. Overall, the findings indicate that there are overall gains in working memory capacity, emotion regulation, and decreased levels and symptoms of anxiety after emotional working memory training.

3.2 The Effectiveness of Emotional Working Memory Training in Clinical Population

From the above discussions, it is evident that emotional working memory training can be helpful with emotion regulation in typically developing populations. In particular, impaired emotional working memory capacity can contribute to emotion dysregulation and symptoms of clinical disorders. Therefore, it is critical to understand whether these effects transfer into clinical populations as they can help develop effective clinical interventions.

Larsen et al. evaluated whether emotional working memory training can be applied to an adult sample of veterans (18–70 years) with PTSD using a set of questionnaires, cognitive and working memory tasks, and a follow-up session after a month [11]. The participants were randomly assigned to one of two groups: the active or control emotional working memory training group. The trainings utilized an adaptive dual n-back task. Each training session began at the 1-back level, and the difficulty increased by one level if there was 95% accuracy in performance at the level. However, it would decrease by one level if there was below a 75% accuracy in performance. In contrast, the control group had the identical training, but it only consisted of and remained at the first level regardless of performance. The findings demonstrated in terms of PTSD symptoms and working memory improvements, there was little difference between the two groups. Nonetheless, in comparison to the control group, the active training group marginally outperformed in improving reexperiencing symptoms of PTSD. Additionally, there was a significant decrease in PTSD symptoms in both the active and control working memory groups. Interestingly, participants in both conditions found the working memory training interventions quite challenging. Accordingly, the results indicate a significant decrease in PTSD symptoms following working memory training.

4 Conclusion

As evidenced by the above discussions, working memory capacity levels and emotion regulation abilities are related. In particular, in typically developing populations, individuals with higher working memory capacity are more adept at regulating their emotional responses, and that impaired working memory capacity might contribute to anxious states. Subsequently, deficits in working memory capacity can contribute to emotion

dysregulation and clinical disorders, as the findings indicate that there are impairments in working memory capacity in clinical populations with MDD and PTSD. In terms of emotional working memory training, the results suggest that in typically developing populations, emotional working memory training increased working memory capacity, emotion regulation and function, and reduced anxiety levels and symptoms. In clinical populations with PTSD, working memory training increased working memory capacity and decreased PTSD symptoms. Overall, these findings demonstrate the development of working memory training programs might be a beneficial intervention treatment.

However, there were some limitations with the above studies. The majority of the studies investigating working memory training were not longitudinal studies and did not follow up on the participants after a long period of time. Thus, it is difficult to understand and assess the long-term effectiveness of working memory training interventions, which is particularly important in developing interventions for clinical populations. In addition, the studies measured emotion regulation and symptoms using questionnaires or computerized tasks completed by participants, which are subjective measures or measures in a lab setting respectively. These results cannot reflect performances in real-life settings objectively. As a result, it is difficult to examine whether emotion regulation objectively improved in real-life situations. Future studies should conduct longitudinal measurements to evaluate working memory training interventions' long-term effectiveness, to develop more engaging and effective training paradigms. In addition, future studies should also develop better measurements of assessing emotion regulation that can be more objective and reflect real-life functions. This review can provide some guidance to future intervention studies and practices in the area of emotion regulation.

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