INFLUENCE OF PROPOSITIONAL DENSITY ON THE FORMATION AND RETENTION OF EPISODIC MEMORIES

by

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Influence of Propositional Density on Formation and Retention of Episodic Memories

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Psychology at George Mason University

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Abstract

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Episodic memory (EM) plays a pivotal role in our daily lives, allowing us to remember distinct events throughout our lifetime. However, EM is susceptible to normal aging and neuropathology, raising the question of whether we can improve EM by training. This thesis examined the influence EM training has on EM formation and retrieval and on fluid intelligence (Gf), as well as the role working memory (WM), and propositional density plays in EM training. 62 young adults were randomly assigned to experimental (EM training) or control conditions (no EM training). Stories written by the experimental group were analyzed for propositional density scores. EM, WM, Gf, and attention were then recorded both before and after training sessions for both groups. We found evidence of EM improvement from training, as well as WM ability being able to influence EM training performance. Findings related to propositional density showed mixed results, although there was some evidence of propositional density increasing throughout EM

training. These findings allow us to gain a better understanding of the underlying processes of EM training, as well as its relationship to WM and propositional density.

Introduction

Episodic memory (EM) is important for daily life, allowing people to encode past experiences of distinct events – in some cases forming memories lasting as long as life itself. However, EM is also vulnerable to normal aging (Kirchhoff, 2011) and neuropathology (Rémy, 2015). That raises the question of whether EM can be improved by training. There is some evidence, albeit controversial, that working memory training is effective in inducing far transfer to Gf (e.g., meta-analysis of Au et al., 2014), but EM training has received much less attention. Indeed, a prominent EM researcher, Ranganath (2011), suggested that formal training may not change encoding and retrieval processes of EM, insofar as ongoing memory formation and retrieval continuously engage the medial temporal lobe structures (MTL) associated with EM formation. The training literature has reported transfer of training to episodic memory from (a) perceptual training (Mahncke et al., 2006; Smith et al., 2009, others), (b) working memory training (Buschkuehl et al., 2008; Rudebeck, et al., 2012; Au et al., 2014), (c) executive function training (Jennings & Jacoby, 2003). The question we address is whether training on EM per se can improve EM performance. Much of the previous work on EM training has trained mnemonic strategies, such as the method of loci (Verhaeghen, et al., 1992; Lustig, et al., 2009). However, that approach has not been found to consistently generalize (Brigham & Pressley, 1988; reviewed in Ranganath, 2011). A more direct approach is to directly train the abilities to form and retrieve EM by requiring repeated formation and retrieval of EM of novel information. We hypothesized that such EM training would lead to improved EM formation and retrieval over days. Much is unknown about what factors influence ability to form and retrieve EM (Ranganath, 2011), including the role of WM in LTM formation (Ranganath, 2005). Important for the transfer from WM to LTM is ability to encode stimuli with sufficient contextual cues to facilitate later retrieval (Unsworth & Engle, 2007). Based on evidence that measures of WM are moderately to strongly related to measures of long-term memory (Mogle, Lovett, Stawski, & Sliwinski, 2008; Unsworth, Brewer, & Spillers, 2009), we hypothesized that baseline WM ability can influence both EM accuracy and an increase in EM accuracy with training. Another question concerns the effects of EM training on Gf. There is growing, albeit controversial literature showing WM training can improve Gf (Au et al., 2014; Karbach & Kray, 2009). That WM training can heighten both EM and Gf (Rudebeck, et al. 2012) suggests a relationship between those two abilities. There is evidence that cognitive training affects neural plasticity (White-Schwoch et al., 2013; Anderson et al. 2013) and the "neural efficiency" hypothesis argues that cognitive training may increase neural efficiency (Neubauer & Fink, 2009). We hypothesized that EM training may increase neural efficiency, and be reflected in Gf.

Another factor important in EM formation is contextual richness, the number of circumstances which form the setting of an event and which then bind together to create a coherent episodic memory (Uncapher et al., 2006). Contextual richness is characteristic of EM (Uncapher et al., 2006; Morcom et al., 2007) and retrieval of episodic memory involves contextual reinstatement (Uncapher et al., 2006) seen in reactivation of the brain regions that were engaged during the original encoding event (Morcom et al., 2007). The importance of context to episodic memory raises the question of whether propositional density provides additional context for EM and thereby promotes encoding and retrieval. Propositional density, defined as the average number of ideas/propositions expressed in a text sample divided by the number of words, has long been studied for its relation to cognitive reserve in older people (Scarmeas & Stern, 2003; Kemper, 2001; Engleman et al., 2010). The role of propositional density in EM in EM formation and retrieval has not been previously investigated to our knowledge. Based on this evidence, we hypothesized that episodic memories that are characterized by greater propositional density in their stories would show superior retrieval.

EM formation and its possible modulation by training

As previously stated, there is evidence that EM can be enhanced through perceptual (Mahncke et al., 2006), WM (Buschkuehl et al., 2008), and frontal executive (Jennings & Jacoby, 2003) training. In addition, electroencephalography (EEG) has been used to compare neural oscillations during different WM tasks, finding that theta oscillations increased in prefrontal sites during temporal information maintenance, while alpha oscillations increased in posterior parietal and lateral occipital sites during spatial information maintenance (Hsieh, Ekstrom, Ranganath, 2011). This evidence supports the idea that theta and alpha oscillations are related to different aspects of WM, and specific training procedures may only affect these aspects in different ways (Hsieh et al., 2011).

Indeed, evidence suggests that temporal information maintenance is linked heavily to hippocampus activity and may play a critical role in EM (Hsieh et al., 2014). However, training tasks have focused on procedures that increase the effectiveness of encoding and retrieval processes, rather than on training tasks which tax the MTL (Ranganath, 2011). The focus of many of these studies has been on the effects of these types of training on participant's WM rather than on EM (Ranganath et al., 2011). Although research suggests that EM training has beneficial effects on EM, most of these studies focus on variables other than EM, causing a lack of generalization (Ranganath et al., 2011). However, the few studies which have focused on the beneficial effects of EM training in humans have indeed shown that EM training is effective in increasing EM (Kirchhoff, 2011; Hertzog et al., 1998). Beneficial effects of EM training in older adults have been seen in an increase of cortical thickness in the right orbitofrontal gyrus, insula, and fusiform gyrus (Engvig et al., 2010), increased choline and creatine signals in the hippocampus (Valenzuela et al., 2003), and increased activation in the occipitoparietal cortex (Nyberg et al., 2003).

Role of context in EM formation and retrieval

EM has two key features which differentiate it from other forms of memory. First it involves the encoding and retrieval of context information (Flegal et al., 2014). Second it involves "recollective experience," the subjective sense that an event occurred in one's personal past (Flegal et al., 2014). Research indicates there are specific brain regions tied to encoding, retrieval, and re-experience, with findings focused on the medial temporal, parietal, and prefrontal cortices (Flegal et al., 2014). Specifically, the collective role of the MTL, medial prefrontal cortex, angular gyrus (AnG), and posterior cingulate cortex (PCC) have been referred to as the "general recollection network", and have been shown to increase activation during the retrieval of contextual information (Flegal et al., 2014). However, there is evidence that some of these components of the general recollection network may only be critical for context processing, whereas others may only be critical for recollective experience (Vann et al., 2009). There is fMRI evidence of regional specificity within these brain regions, with the hippocampus and parahippocampal cortex showing increased activity during the retrieval and processing of semantic context (Flegal et al., 2014). This suggests that within the recollective network, these two MTL structures play a key role in context processing. In contrast, fMRI results have shown that parietal (AnG and PCC) and prefrontal (PFC) components of the general recollection network are related to context-independent effects, suggesting that these regions are more closely related to remembering (Flegal et al., 2014). This suggests that the substrate responsible for EM formation plays a role in the encoding processes in the hippocampus and parahippocampal cortex (Flegal et al., 2014).

Similarly, it has been argued that various features comprising an episode must be brought together from different cortical regions outside of the hippocampus and parahippocampal cortex, to form contextually rich EMs (Uncapher et al., 2006). Uncapher et al. (2006) found that during the processing/retrieval of a specific feature of an event such as the color of an object, there was similar brain activity in the hippocampus and cortical regions involved when that specific feature (e.g. color) was encoded. However, when multiple features of are successfully retrieved (e.g. color and location) there are additional cortical regions involved that weren't involved when the features were retrieved individually (Uncapher et al., 2006). Among these regions, the intraparietal sulcus is claimed to be the main support of this attentionally-mediated perceptual binding (Uncapher et al., 2006). By binding multiple features of an episode together at a perceptual level, EMs are able to change in their contextual richness (Uncapher et al., 2006).

Propositional density is defined as the average number of ideas/propositions expressed in a text sample divided by the number of words (Baynes, 2016). These ideas/propositions often correspond to a verb, adjective, adverb, or propositional phrase. Propositional density has been used as a measurement tool for a variety of measures including semantic content: (a) amount of information packed into a sentence (Baynes, 2016); (b) predictor of cognitive reserve (Snowdon et al., 1996); (c) processing efficiency. Processing efficiency is the amount of information that can be processed at one time (Kemper & Sumner, 2001). Processing efficiency has been associated with whether ideas are expressed succinctly and with the verbal retrieval of words (Kemper & Sumner, 2001). Previous research on propositional density has mostly focused on the role it plays in predicting future cognitive ability in old age, particularly in predicting incidence of Alzheimer's Disease, a disease where EM is often one of the first and most pronounced deficits to develop (Snowdon et al.,1996). Even when measured in later life, propositional density is able to predict the trajectory for cognitive changes over a 4 year period in healthy older adults (Farias et al., 2012). Furthermore, propositional density scores are found to gradually decline in healthy older adults, with the most pronounced decline occurring in one's mid-70s, whereas, older adults with dementia showed a much more drastic decline regardless of age. Of these older adults with dementia, the ones with higher initial propositional density (and higher overall cognitive reserve) experienced a much more rapid decline in propositional density scores (Kemper et al., 2001). Although the specific relationship between propositional density and WM and EM has not yet been established, further analysis of this relationship of propositional density to these basic memory abilities may allow us to gain a better understanding of the cognitive abilities that influence effectiveness of episodic memory training (Kemper & Sumner, 2001).

Specific Aims

Although previous research suggests that EM training by use of mnemonics and strategies has beneficial effects on EM (Verhaeghen, et al., 1992; Lustig, et al., 2009), the extent to which such strategies generalize beyond the original training circumstances appears to vary across studies (reviewed in Ranganath et al., 2011). Less is known about the effect of directly training EM abilities. In addition, much is unknown about other cognitive abilities which influence the ability to both form and retrieve EM, including the role of WM in forming LTM (Unsworth & Engle, 2007), as well as the role of propositional density in both EM and WM (Kemper & Sumner, 2001). This raises important questions about the effectiveness of EM training and about the roles of WM and propositional density in EM training.

Aim 1. To determine the effects of EM training on ability to form and retain EM. We hypothesized that (a) EM training over 4 days by daily requirements for demanding EM formation and for retrieval over days would lead to improvement in EM performance. If the predicted outcomes are observed, that evidence can be interpreted as indicating that EM formation and retrieval benefits from strong and novel demands on those abilities. If the predicted outcomes are not observed, the evidence can be interpreted as indicating a failure of repeated formation and retrieval of a large number of new memories to benefit EM ability. The current design does not address the long-term effects of EM training.

Aim 2. To determine the effects of baseline WM performance on benefits of EM training and EM performance. We hypothesized that (b) baseline WM ability influences EM accuracy during the training procedure. If the predicted outcomes are observed, evidence of the relationship between WM and EM training would be further supported. If these outcomes are not observed, that would provide evidence that WM does not benefit EM ability.

Aim 3. To determine the effect of propositional density on EM formation, EM training, EM performance, and WM performance. We hypothesized (c) baseline WM would predict propositional density scores, (d) average propositional density scores would increase across training days, (e) those participants who write stories with greater propositional density scores would show superior retrieval of all stories and (f) higher EM post-test scores. If these predictions are supported, this will be the first study to provide evidence on the effects of propositional density on EM training, EM performance, and WM performance. If these outcomes are not observed, that would provides evidence that propositional density does not have an effect on EM training, EM performance, and WM performance.

Parent Study

This thesis is part of a larger study that is focused on epigenetic changes related to EM training. In what follows, a brief background is provided on the parent study, hypotheses of which are not included in the present thesis.

EM allows people to “re-experience” an event that occurred in the past, one with a “time-stamped” quality. There is increasing evidence that EM is encoded by epigenetic changes. Durable epigenetic changes in the form of DNA methylation of glucocorticoid receptor (GR) genes are well-documented in hippocampus of individuals maltreated when young (reviewed in McGowan, 2013; McGowan, 2009). Synaptic-dependent mechanisms have been found to regulate BDNF gene expression by alterations in DNA methylation (Tian et al., 2010) and changes in DNA methylation can be detected in peripherally collected monocytes (e.g, Tyrka, et al., 2012). Brain changes associated with EM encoding occur very rapidly – within 24 hrs in epigenetic changes in animal work (Pavlopoulos et al., 2013) and within minutes in neuronal firing in human work (Ison et al., 2015). Based on this, we hypothesized (a) EM training would lead to rapid behavioral changes over days and (b) peripheral monocytes would reflect DNA methylation as a function of EM training performance, assessed across the genome.

There is growing evidence of an epigenetic component to the substrate of EM formation specifically. Pavlopoulos et al. (2013) looked at gene expression in postmortem samples of dentate gyrus (DG) from older people who were cognitively intact at death. The DG is well-known to be the site of age-related change. Of the 17 identified transcripts in the DG, RbAp48 – a transcriptional regulator with a role in histone acetylation - was selected as having among the strongest decrease in expression with age. They then turned to mice to examine the function of the RbAp48 gene, which was subsequently shown to undergo histone modification in 24 hours in a manner that influenced the formation of episodic memories tested in a novel object task (Pavlopoulos et al., 2013). Although some methylation changes may be short-lived, evidence from humans suggests long-duration changes (McGowan, 2009). Based on that evidence of rapid epigenetic changes associated with EM formation in animals, we hypothesized that EM formation and retrieval is associated with changes in DNA methylation measured in peripherally collected monocytes. We further hypothesized that changes in DNA methylation would occur in concert with increased functional connectivity (fcMRI) in the default mode network, due to strong demands on memory retrieval. This was assessed in fMRI scanning. The fcMRI and epigenetic data was analyzed separately from the present study.

Materials and Methods

62 young adults, between age 18-30 participated in this study. Participants were recruited from SONA research pools at George Mason University, and gave informed consent in accordance with George Mason University's Office of Research Integrity & Assurance guidelines. All participants were right-handed, had English as a primary (learned from birth) or secondary language (learned after primary language), scored at least 20/30 on both the Snellen and Rosenbaum pocket screener, reported no current or planned treatment by a psychologist or psychiatrist, and were not taking any psychoactive medication. Participants were given required class credits, as well as $15 an hour after their credit quota was met, providing incentives to continue with the study, and lowering dropout rates to 10.29% (7 participants). Table 1 further provides basic demographic information of participants.

Table 1

Demographic Information

Gender	Number	Average Age	English Primary Language	English Secondary Language
Male	22	19.68	19	3
Female	39	19.33	33	6
Total	61	19.45	52	10

Note. 7 participants (3 male, 4 female) were dropped from the study and are therefore not included in the table. Of these 7, 5 withdrew from the study and 2 were removed due to abnormal RAPM pre-test scores.

To test the hypotheses (stated on page 8-9), participants were randomly assigned to either the training group or the minimal-contact control group. As shown in Table 2, we performed a one-way ANOVA to verify our groups did not differ statistically on the pre-test for measures of EM and Gf.

Table 2

Group Comparison on Pre-test

Measurement	Condition	*df*	*F*	*Sig*
Fluid Intelligence	EPT	60	.511	.478
	RAPM	60	1.945	.168
	BOMAT	32	.076	.785
Episodic Memory	WMSi	60	.906	.345
	WMSd	60	.120	.731

Note: *p < 0.1. **p < .05

The 20 participants in the minimal-contact control group underwent pre- and post-training assessment, but did not undergo training. They were asked to fill out a set of online survey questions about their daily activities each day for 4 days. The 41 participants in the training group underwent 4 days of EM training. On each of the 4 training days they were required to create their own story based an ordered set of 5 randomly selected images of various indoor and outdoor scenes including people and animals. The story was required to be based on the chronological order of the images. Each story is defined as a trial. Fig. 1 provides an example of a trial and story.

Figure 1. Trial image presented during the training task. Participants would write a story based on the chronological order of the images such as,"As I was knitting, a horse crashed into my camera. The horse was running away from a ram while a dog barked loudly."

After writing 5 sets of stories, participants were tested by requiring them to indicate the correct story order of the images in each of these 5 trials (one trial block). This training continued until either 1 hour of time elapsed, or 5 trial blocks were completed. On subsequent training days, participants returned to the laboratory to be both tested on (a) 12 stories/trials from previous days and (b) new stories. When a participant incorrectly ordered pictures in a trial during the test, they were shown their story to re-read and were then re-tested on the same trial. This repeated until the participant ordered pictures in the trial correctly or failed 3 times. Participants were tested on their accuracy after 0, 24, 48, and 72 hours.

Propositional Density scores were analyzed by submitting these stories to the well-established Computerized Propositional Idea Density Rater (CPIDR), a computer program which analyzes propositional density of submitted English text based on parts-of-speech tags (Brown et al., 2008). CPIDR determines the total number of propositions expressed in the story and divides this amount by the total number of words (Brown et al., 2008).

Transfer tasks. Before and after training, participants were assessed with a cognitive battery. As our hypotheses make specific predictions about the effect of EM training on EM, we assessed cognition more broadly, assessing WM, visual attention, and Gf. Visual attention was assessed in a cued visual search task (CVS, e.g., Greenwood et al., 2000; 2005). Working memory was tested via a temporal working memory (TWM) task (Jenkins and Ranganath, 2010), a spatial working memory (SWM) (Greenwood et al., 2000; 2005), and a task assessing both temporal and spatial working memory (TSWM, Roberts et al., 2013). Episodic memory was tested with the Wechsler Memory Scale (WMS, Wechsler, 1997) logical memory subtests (immediate recall and delayed recall). Fluid intelligence was tested via the Everyday Problems Test (EPT, Willis and Marsiske, 1994), Raven's Advanced Progressive Matrices (RAPM, Ravens, 1998) and Bochumer Matrices Test (BOMAT, Moody, 2009). Table 3 provides an overview of each transfer task, its abbreviation, and the ability measured. These tasks are described in detail below.

Table 3

Transfer Task Overview

Name	Abbreviation	Measurement
Cued Visual Search Task	CVS	Attention and Reaction Time
Temporal Working Memory Task	TWM	Temporal Spatial Memory
Spatial Working Memory Task	SWM	Spatial Working Memory
Temporal and Spatial Working Memory Task	TSWM	Temporal and Spatial Working Memory
Weschler Memory Scale (immediate)	WMSi	Episodic Memory (immediate recall)
Weschler Memory Scale (delayed)	WMSd	Episodic Memory (delayed recall)
Everyday Problems Test	EPT	Fluid Intelligence
Raven's Advanced Progressive Matrices	RAPM	Fluid Intelligence
Bochumer Matrices Test	BOMAT	Fluid Intelligence

Cued visual search task (CVS). The purpose of this task is to act as a control task with a minimal memory load. We predict there would be no training-related change on this task between the control group and training group. This is a visual search task in which the target is a pink "T" presented in a 15 letter search array composed of T, N, G colored pink, blue, or green. Participants were first shown a fixation. After the fixation (1,000 ms), a rectangular precue of variable size is presented in which the target appears embedded in distracters. The rectangular precue varies in size based on the number of letters enclosed (1, 3, 9 , or 15 letters). Participants were asked to respond as quickly as possible to indicate whether the target is present.

Temporal working memory task (TWM). The purpose of this task is to examine temporal working memory. We included it to assess whether baseline temporal WM ability influences EM training and whether EM training transfers to temporal WM. Based on evidence that suggests a relationship between EM and WM (Mogle, Lovett, Stawski, & Sliwinski, 2008; Unsworth, Brewer, & Spillers, 2009) we predicted that baseline WM would be able to predict EM during training. In this task participants were presented with an image and were asked to rate the likelihood it would appear in the average household on a scale of 1 (very unlikely) to 5 (highly likely). After 3 minutes of trials, participants were asked to respond to simple math problems (addition and subtraction) according to whether they were true or false. After 1 minute of math problems, participants were shown 2 images (one left side of screen, one right side of screen) from the first set of trials and were asked to determine which one of these images came first in order as well as rating their confidence in their response.

Spatial working memory task (SWM). The purpose of this transfer task is to examine spatial working memory. We included it to assess whether baseline temporal spatial WM ability influences EM training and whether EM training transfers to spatial WM. It was predicted that EM training would benefit spatial WM. In this task participants were shown a fixation. After the fixation, 1-3 black dots appear on the screen. After another fixation 1 red dot would appear on the screen alone. Participants were asked whether the red dot appeared in the same location as one of the black dots or a different location.

Temporal and spatial working memory task (TSWM). The purpose of this task is to examine temporal and spatial WM. It was predicted that EM training would benefit both temporal and spatial WM. In this study participants were first shown an instruction stating either "location" or "order." After 2 seconds participants were shown 4 variable simple geometric shapes, one at a time for 1 second at each corner of the screen. The order in which the shape appears in each corner is variable. After 2 seconds participants were presented with a target of one of the 4 shown geometric shapes or a new geometric shape. When the instruction is "order," participants were asked the chronological/temporal order in which the target shape appeared (1st, 2nd, 3rd, and 4th). When the instruction is "location," participants were asked the spatial location of the target geometric shape (top right, top left, bottom right, bottom left). If the target geometric shape was not presented in the trial, participants were asked to press a corresponding button number.

Wechsler Memory Scale (WMS), logical memory. Logical memory is a subtest of the standardized Wechsler memory Scale. We used this test of EM to assess whether EM training by repeated encoding and retrieval over 4 days would improve EM performance. It was predicted that EM training would lead to a significant increase in this measure of EM. Participants were read a short story of 4-5 lines. They were then immediately asked to repeat the story back exactly as told (immediate recall). After 30 minutes performing other tasks, participants were again asked to repeat the story back exactly as told (delayed recall). They were not informed in advance about the delayed recall test.

Everyday Problems Test (EPT). The EPT is an everyday-type test of Gf. We have previously found that perceptual training (Strenziok et al., 2014) and WM (Cisler et al., 2015) transfers to the EPT. The EPT was included to examine the effects of EM training on Gf. Although there is little previous evidence on the relationship between EM training and Gf, it was predicted that there would be improvements in Gf in the training group scores, due to improved neural efficiency (Neubauer & Fink, 2009). In this task participants were presented with a 42 item, multiple choice test containing questions on everyday problems such as shopping lists and credit card applications.

Raven's Advanced Progressive Matrices (RAPM). The RAPM is considered a standardized non-verbal test of Gf. The purpose of including this transfer task is to examine the effects of EM training on Gf. Similar to other measures of Gf it is predicted that there would be improvements in Gf in the training group scores. The RAPM consists of 36 geometric pattern-based questions. Participants were presented with 18 randomly assigned geometric pattern-based questions for the pre-test, and the other 18 were used for the post-test. In this task participants were shown a large square containing 8 geometric images and 1 blank image. Participants were given 8 geometric images and were asked which one best fits the blank space in the square based on the pattern.

Bochumer Matrices Test (BOMAT). The BOMAT is very similar to the RAPM therefore, it is a test of Gf. It is very similar to the RAPM, but more difficult and so is better suited to our undergraduate population. The purpose of including this transfer task is to examine the effects of EM training on Gf. Similar to other measures of Gf it is predicted that there would be improvements in Gf in the training group scores. In this task participants were presented with 27 geometric pattern-based questions. Participants were shown a large rectangle containing 14 geometric images and 1 blank image. Participants were given 6 geometric images and were asked which one best fits the blank space in the rectangle based on the pattern.

Parent Study Materials and Methods

Participants underwent MRI safety screening and consent to make sure they were eligible to be scanned. Participants were scanned both before and after the training procedure. MRI scans took 37 minutes and were taken at the Krasnow Institute in George Mason University. Sequences included MPRAGE, a resting state scan (fcMRI), and 4 DTI sequences. Participants were not dropped from the study if they were not eligible to be scanned.

Participants had their blood drawn both before and after training for epigenetic analysis at Student Health Services in George Mason University by a registered phlebotomist.

Analyses

Two fundamental goals of this study were to determine whether (a) EM training transfers to untrained abilities, including Gf and (b) EM training can improve EM. To that end, this study administered 9 transfer tasks, designed to assess EM (WMS immediate and delayed), Gf (EPT, RAPM, BOMAT), attention (CVS), and WM (SWM, TWM, TSWM). We tested the prediction that EM training improves EM, predicting measures of EM (WMS, logical memory, immediate and delayed) would show significant benefits from EM training, as well as transfer to WM (Hsieh et al., 2011) and Gf (Neubauer & Fink, 2009). We performed a MANOVA on post-pre transfer task scores with a between subjects factor of group (EM training, control). In addition, to account for EM improvements we performed a repeated measures analysis on WMS immediate and delayed, regressed WMS (immediate and delayed) pre-test scores against EM accuracy during training (0, 24, 48, 72 hour recall), regressed EM accuracy during training (0, 24, 48, 72 hour recall) against WMS (immediate and delayed) post-test scores, and performed a repeated measures analysis on EM accuracy during immediate recall accuracy during training on same day.

Another fundamental goal of this study was to determine the effects of WM performance on EM training. Based on evidence that baseline WM ability predicts both EM accuracy and increases EM accuracy with training (Ranganath, 2005), we predicted that participants with higher baseline temporal WM ability would attain higher EM accuracy on EM training task. Because evidence shows differential effects of temporal and spatial WM based on the EM training procedure (Hsieh et al., 2011), we examined measures of both temporal and spatial WM. In order to estimate the relationship between WM ability and EM training improvement TWM, SWM, and TSWM pre-scores were regressed against average accuracy scores for each individual recall period during the EM training task. We examined both temporal measures of WM (temporal TSWM accuracy and TWM accuracy), as well as spatial measures of WM (spatial TSWM accuracy and SWM accuracy).

Our final goal was to determine the effect of propositional density in EM formation in EM formation, EM training, EM performance, and WM performance. Based on contextual richness being a characteristic of both EM (Uncapher et al., 2006; Morcom et al., 2007) and propositional density (Kemper & Sumner, 2001) it was predicted that propositional density scores would increase over training days, and that greater propositional density scores would be associated with greater benefits of EM accuracy during EM training and EM post-test scores. We analyzed improvements in propositional density scores across training days by averaging CPIDR scores over each day of training and performing a repeated measures ANOVA with days of training as the within factor. The effects of propositional density scores on EM training accuracy were analyzed by running a Pearson's correlation between average CPIDR scores of participant's EM training day stories and their EM accuracy during each individual recall period. The effects of propositional density scores on EM post-test score accuracy were analyzed by running a linear regression to see if average CPIDR score could predict EM post-test score. Based on propositional density being a measurement semantic content (Baynes, 2016) and processing efficiency (Kemper & Sumner, 2001), it was predicted that participants with higher baseline WM ability would attain higher propositional density on the EM training task. In order to estimate the relationship between WM ability and propositional density, temporal (TWM and temporal TSWM) and spatial (SWM and spatial TSWM) WM pre-test scores were regressed against total average CPIDR scores.

Results

Omnibus Analysis of EM training effects on transfer tasks

We tested the hypotheses that (a) EM training transfers to untrained abilities, including Gf and (b) EM training improves EM performance. We used a MANOVA (Table 4) to conduct an omnibus analysis of the effects of EM training on untrained abilities. We calculated post-pre transfer task difference scores (SWM, TWM, TSWM, EPT, RAPM, CVS), and performed a MANOVA on those scores with a between subjects factor of group (EM training, control). Due to experimenter error in collecting BOMAT data, BOMAT scores were removed from the MANOVA in order to maintain an acceptable sample size for these analyses. The MANOVA revealed a significant effect of EM training (Wilks' Lambda = .634, p = .038).

Table 4					
MANOVA on Transfer Tasks					
Effect of Condition	*Value*	*F*	*Sig.*	η^2	*Observed Power*
Wilks' Lambda	.634	2.380	0.038**	.366	.807
Univariate ANOVA on Transfer Tasks					
Task	*df*	*F*	*Sig.*	η^2	*Observed Power*
CVS Response Time	41	3.278	.078*	.078	.423
SWM Accuracy	41	1.649	.207	.041	.240
TWM Accuracy	41	1.086	.316	.026	.168
TSWM Spatial Accuracy	41	2.363	.132	.057	.323
TSWM Temporal Accuracy	41	.344	.561	.009	.088
EPT Accuracy	41	1.086	.304	.027	.174
RAPM Accuracy	41	4.525	.040*	.104	.546
RAPM Time	41	.860	.360	.022	.148
Note: *p <0.1.**p < .05					

A follow-up univariate ANOVA revealed that RAPM post-pre difference scores were greater in control group participants, $F(1,40)= 4.525$, $p = .040$. Additionally, there was a trending effect of improvement in experimental participants for CVS $F(1,40)= 3.278$, $p = .078$. No other univariate tests were significant. To better understand the RAPM findings, we conducted a repeated measures ANOVA on RAPM pre- and post-scores for the two groups. Although there was a trending effect for condition, $F(1,59)= 3.031$, $p = .087$, $\eta^2 = .049$, power = .402, Fig. 2 shows the mean of the control groups RAPM pre-test (*M*=.5111, *SD*=.1753) was far below the mean of the experimental groups RAPM pre-test (*M*=.5814, *SD*=.1890), and the mean of the control group's RAPM post-test (*M*=.5861, *SD*=.1459) did not exceed the mean of the experimental group's RAPM post-test (*M*=.5894, *SD*=.2018).

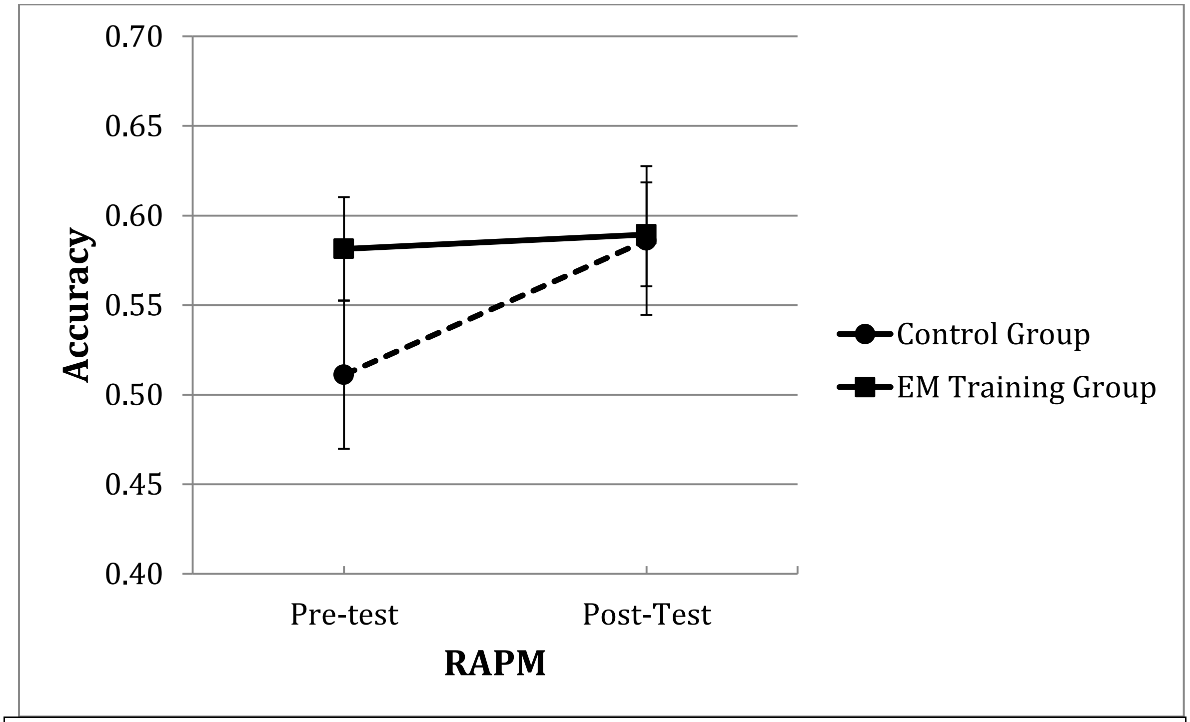

*Figure 2.*Accuracy of performance on the RAPM task at pre- and post-training sessions for each group. Error bars are the standard error of the mean.

To test the prediction that EM training improved EM, we conducted a repeated measures analysis comparing WMS logical memory immediate and delayed on pre- and post-training assessments. Figure 3 shows WMSi increased after training, but only at a marginal level of significance $F(1,59)= 3.056$, $p= .086$, $\eta^2 = .049$, power = .405. The mean of the control groups WMSi pre-test (*M*=.3760, *SD*=.1156) showed little change in the WMSi post-test (*M*=.3900, *SD*=.1696), whereas, the mean of the experimental groups WMSi pre-test (*M*=.3356, *SD*=.1283) showed improvement in the WMSi post-test

(*M*=.4205, *SD*=.1500) (Fig. 3). The repeated measures analysis for WMSd was not significant (Fig. 4).

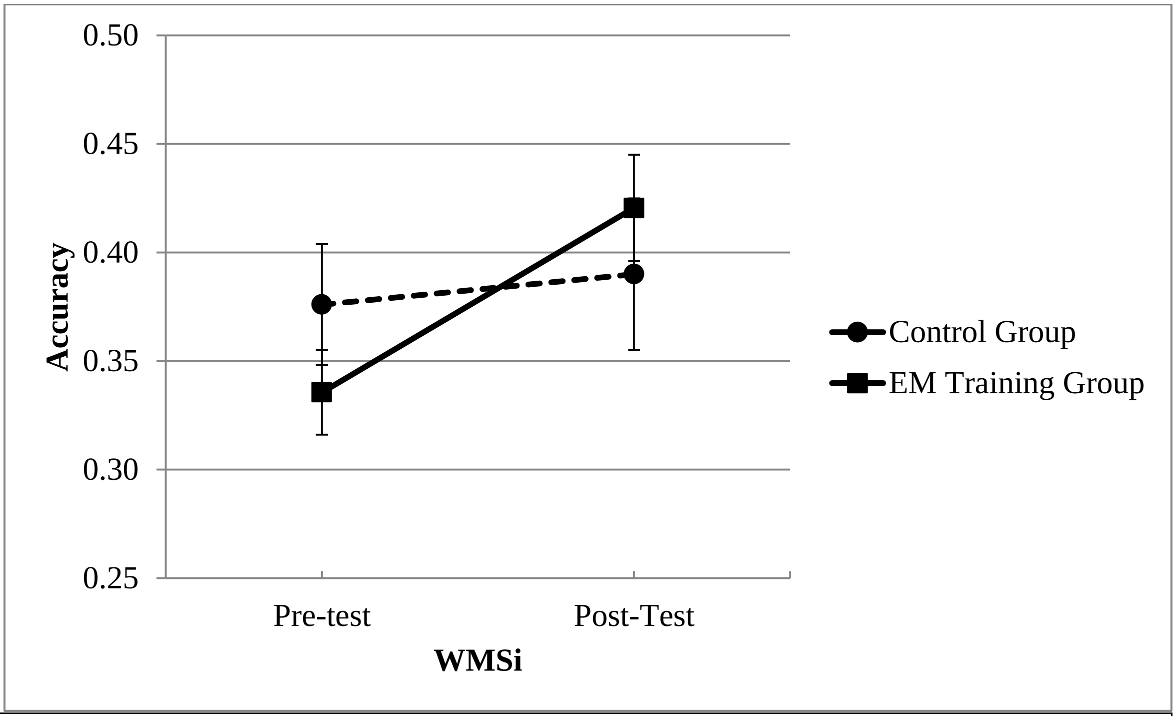

*Figure 3.*Accuracy of performance on the WMSi test at pre- and post-training sessions for each group. Error bars are the standard error of the mean.

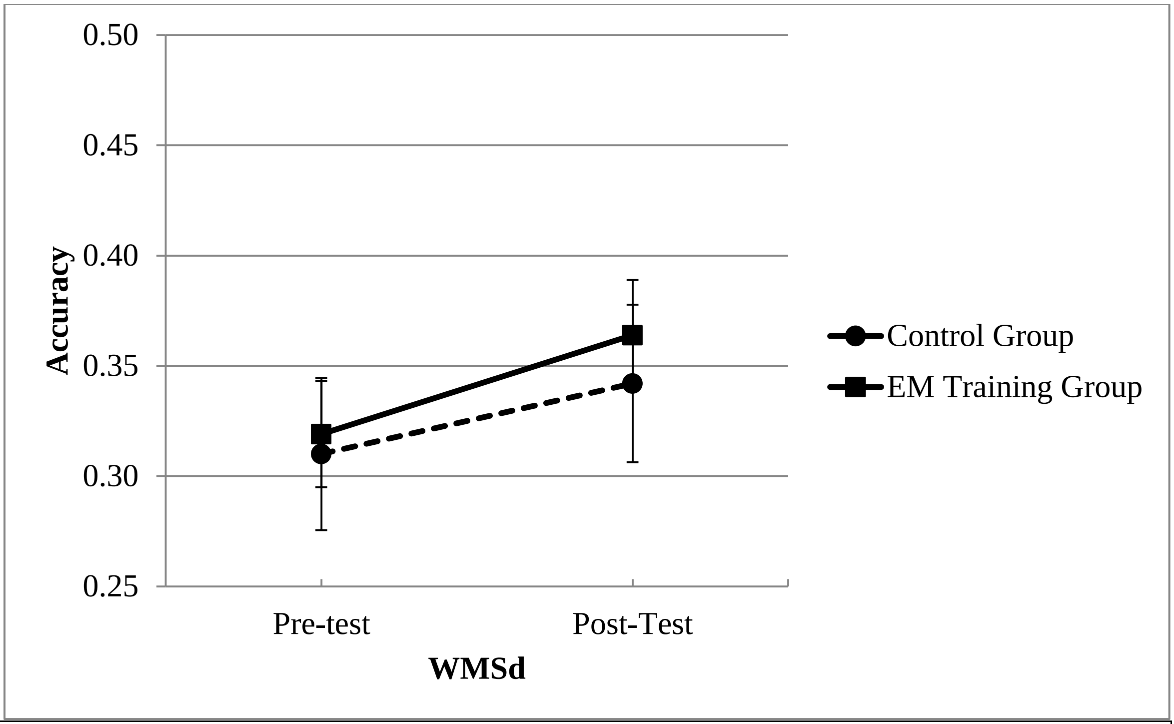

*Figure 4.*Accuracy of performance on the WMSd test at pre- and post-training sessions for each group. Error bars are the standard error of the mean.

Effects of EM training on EM

To further test our hypotheses concerning the relation between baseline EM ability and effects of EM training on EM, we conducted several regression analyses to examine the relationship between the EM training task and EM performance. First, we examined whether baseline WMS performance (immediate and delayed pre-test scores) predicted EM accuracy during the training task. The regression showed WMSi baseline score predicted immediate recall accuracy during training the day a story was encoded initially, $F(1,39)= 4.752$, $p = .035$, and during delayed recall during training at 72 hours after initial encoding, $F(1,39)= 5.029$, $p = .031$. Additionally, there was a trending effect seen for delayed recall accuracy during training 24 hours after initial encoding, $F(1,39)=$

3.017, p = .090 and delayed recall accuracy during training 48 hoursafter initial encoding, $F(1,39)$= 4.025, p = .052 (Table 5).

When testing whether WMSd baseline score predicted recall during the training task, the regression showed WMSd baseline score predicted immediate recall accuracy during training on same day, $F(1,39)$= 8.228, p = .007, delayed recall accuracy during training at 24 hours after initial encoding, $F(1,39)$= 6.024, p = .019, delayed recall accuracy during training at 48 hours after initial encoding, $F(1,39)$= 4.359, p = .043, and delayed recall accuracy during training at 72 hours after initial encoding,$F(1,39)$= 4.479, p = .041 (Table 5).

Table 5							
Regression of WMSi/d Pre-test Scores on Training Day Accuracy							
Task	Recall Accuracy	*R Squared*	*F*	*Sig.*	*B*	*SE B*	*β*
	Immediate Recall Accuracy	.109	4.752	.035**	.085	.039	.330
	Delayed Recall Accuracy at 24 Hours	.072	3.017	.09*	.392	.226	.268
	Delayed Recall Accuracy at 48 Hours	.094	4.025	.052*	.488	.243	.306
WMSi	Delayed Recall Accuracy at 72 Hours	.114	5.029	.031**	.774	.345	.338
	Immediate Recall Accuracy	.174	2.868	.007**	.089	.031	.417
	Delayed Recall Accuracy at 24 Hours	.134	6.024	.019**	.445	.181	.366
	Delayed Recall Accuracy at 48 Hours	.101	4.359	.043**	.421	.202	.317
WMSd	Delayed Recall Accuracy at 72 Hours	.103	4.479	.041**	.612	.289	.321
Note: $*p < 0.1$. $**p < .05$							

We also asked the question of whether recall accuracy (tested 0, 24, 48, 72 hours after initial encoding) could predict WMS (immediate and delayed) post-test scores. Using regression, we found immediate recall accuracy during training on same day was able to predict WMSd post-test scores, $F(1,39) = 4.380$, $p = .043$, and delayed recall accuracy during training at 24 hours after initial encoding was able to predict WMSd post-test scores, $F(1,39) = 5.141$, $p = .029$. Additionally, there was trending significance for delayed recall accuracy during training at 72 hours predicting the WMSd post-test, *F*(1,39)= 3.112, *p* = .086. Furthermore, there was trending significance at immediate recall accuracy during training on same day, *F*(1,39)= 3.128, *p* = .085 and delayed recall accuracy during training at 24 hours after initial encoding, *F*(1,39)= 3.595, *p* = .065 for predicting the WMSi post-test (Table 6).

Table 6

Regression of Training Day Accuracy on WMSi/d Post-test Scores

Recall Accuracy	Task	*R Squared*	*F*	*Sig.*	*B*	*SE B*	*β*
Immediate Recall Accuracy	WMSi	.074	3.128	.085*	1.237	.699	.273
	WMSd	.101	4.380	.043**	1.607	.768	.318
Delayed Recall Accuracy at 24 Hours	WMSi	.084	3.595	.065*	.232	.122	.291
	WMSd	.116	5.141	.029**	.304	.134	.341
Delayed Recall Accuracy at 48 Hours	WMSi	.004	.169	.684	.048	.117	.066
	WMSd	.025	1.007	.322	.129	.129	.159
Delayed Recall Accuracy at 72 Hours	WMSi	.036	1.457	.235	.097	.080	.190
	WMSd	.074	3.112	.086*	.154	.088	.272

Note: **p* <0.1. ***p* < .05

Finally, in order to assess the overall differences between initial memory formation means on different training days, a repeated measures ANOVA was conducted with immediate recall accuracy during training on same day as the within factor. The results failed the test of sphericity, so Greenhouse-Geisser correction was used to test the main effect of new memory recall accuracy, which changed significantly over days *F*(2.55, 99.630)= 3.993, *p* = .014. Results showed a significant linear *F*(1,39)= 4.135, *p* = .049, and quadratic effect $F(1,39) = 7.177$ (Table 7). Additionally, post-hoc comparisons were conducted using the Bonferroni correction. Results showed a significant difference between day 2 and day 4 (*MD*=.025, $p = .008$), and day 3 and day 4 (*MD*=.018, $p = .035$) (Fig. 5). Average new memory recall accuracy on day 1 (*M*=.9726, *SD*=.0349) decreased on the day 2 (*M*=.9594, *SD*=.0580), and then increased on day 3 (*M*=.9660, *SD*=.0513) and day 4(*M*=.9840, *SD*=.0256)

Table 7

Repeated Measures ANOVA of Immediate Recall Accuracy During Training

Effect of Condition	*Value*	*df*	*F*	*Sig.*	η^2	*Observed Power*
Wilks' Lambda	.320	37	5.815	.002**	.320	.929
Greenhouse-Geisser		99.63	3.993	.014**	.093	.777
Linear		39	4.135	.049**	.096	.509
Quadratic		39	7.177	.011**	.155	.743

Note: *p <0.1. **p < .05

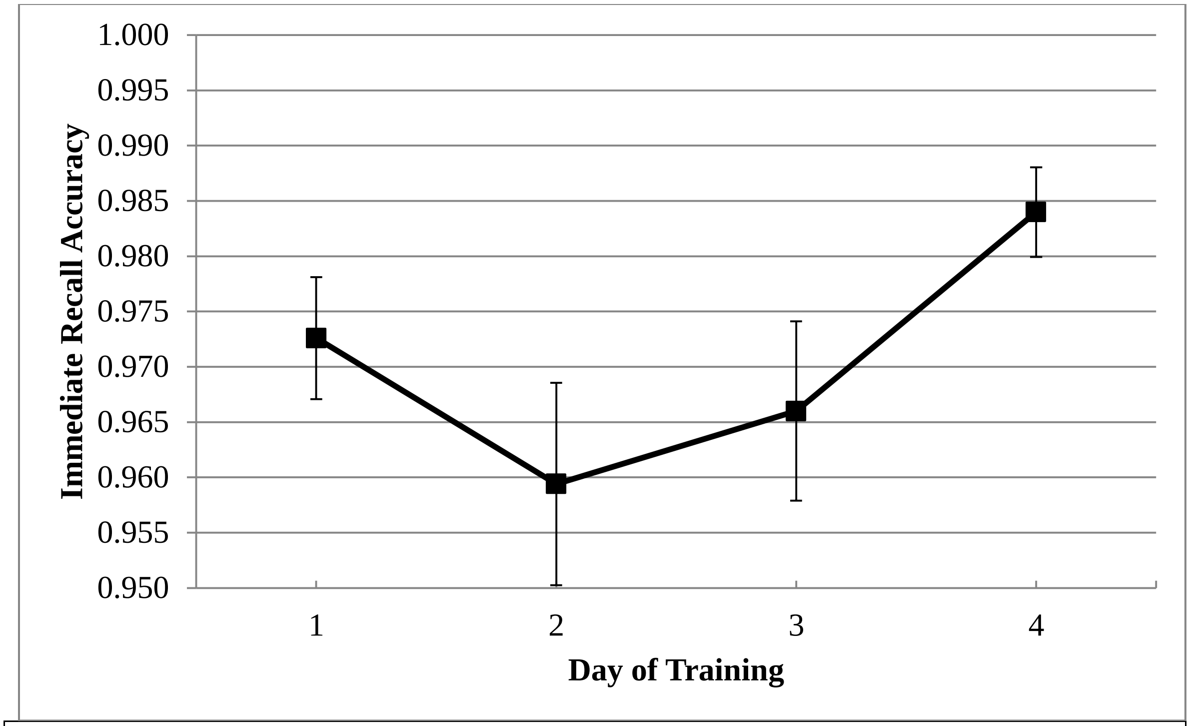

*Figure 5.*Mean immediate recall accuracy during training on each day of training. Error bars are the standard error of the mean.

Effects of baseline WM ability on EM training scores

To test our predictions on the relationship between WM ability and EM training improvement, the following WM pre-training scores, TWM, SWM, and TSWM were regressed against average training recall accuracy at 0, 24, 48, and 72 hours after initial memory formation. A regression analysis allowed us to assess relations between WM baseline and EM performance.

Temporal WM was analyzed by regressing TWM and temporal TSWM pre-training scores against EM recall during training (tested 0, 24, 48, 72 hours after initial encoding). Temporal measures of WM were able to predict immediate recall accuracy during training on same day, $F(2,36)= 3.313$, $p = .048$. Additionally, temporal measures of WM showed a trending effect with delayed recall accuracy during training at 24 hours after initial encoding, $F(2,36)= 2.496$, $p = .097$. However, they were unable to account for the variance for delayed recall accuracy during training at 48 and 72 hours after initial encoding (Table 8).

Table 8

Regression of Temporal Working Memory on Training Day Accuracy

Recall Accuracy	*R Squared*	*F*	*Sig.*	*Task*	*B*	*SE B*	*β*	*Sig.*
Immediate Recall Accuracy	.155	3.313	.048**	TSWM	.062	.025	.387	.019**
				TWM	.006	.036	.027	.867
Delayed Recall Accuracy at 24 Hours	.122	2.496	.097*	TSWM	.320	.150	.344	.040**
				TWM	.025	.213	.019	.909
Delayed Recall Accuracy at 48 Hours	.051	.964	.391	TSWM	.234	.170	.230	.178
				TWM	-.032	.241	-.022	.895
Delayed Recall Accuracy at 72 Hours	.077	.151	.235	TSWM	.259	.232	.185	.271
				TWM	.333	.328	.168	.317

Note: *p <0.1. **p < .05

Spatial WM was analyzed by regressing SWM and spatial TSWM pre-training scores against the average EM recall during training (tested 0, 24, 48, 72 hours after initial encoding). Spatial measures of WM were able to predict immediate recall accuracy during training on same day, $F(2,36)= 7.116$, $p = .002$. Additionally, spatial measures of

WM showed a trending effect with delayed recall accuracy during training 24 hours after initial encoding, $F(2,36) = 3.119$, $p = .056$ and 72 hours after initial encoding, $F(2,36) = 2.567$, $p = .091$. However, those measures were unable to account for the variance for delayed recall accuracy during training at 48 hours (Table 9).

Table 9

Regression of Spatial Working Memory on Training Day Accuracy

Recall Accuracy	*R Squared*	*F*	*Sig.*	*Task*	*B*	*SE B*	*β*	*Sig.*
Immediate Recall Accuracy	.283	7.116	.002**	TSWM	.087	.023	.571	.001**
				SWM	.047	.024	.296	.061*
Delayed Recall Accuracy at 24 Hours	.148	3.119	.056*	TSWM	.359	.145	.414	.018**
				SWM	.183	.151	.202	.234
Delayed Recall Accuracy at 48 Hours	.091	1.803	.179	TSWM	.286	.159	.310	.081
				SWM	.208	.166	.216	.218
Delayed Recall Accuracy at 72 Hours	.125	2.567	.091*	TSWM	.440	.220	.338	.053*
				SWM	.403	.230	.296	.088*

Note: *$p < 0.1$. **$p < .05$

Effects of baseline WM ability on Propositional Density

A direct relationship between WM and propositional density has not been previously investigated. We asked whether characteristics of propositional density could be explained by WM. Propositional density has been shown to be a measurement of processing efficiency (Kemper & Sumner, 2001). Based on that, it was predicted that having greater WM would be associated with better ability to encode information. Specifically, we predicted that baseline WM would be able to account for the average propositional density scores across training days. Due to evidence suggesting differences in brain region activity depending on whether the information was encoded temporally or spatially (Hsieh et al., 2011), we ran separate regressions on measurements of temporal and spatial WM.

In order to test predictions on the relationship between WM ability and propositional density, temporal (TWM and temporal TSWM) and spatial (SWM) and spatial TSWM), WM pre-test scores were regressed against total average CPIDR scores. There were no overall significant findings for temporal, $F(2,36) = 1.024$, $p = .370$ and spatial measures $F(2,36) = .904$, $p = .414$ of WM predicting CPIDR scores (Table 10).

Table 10

Regression of Working Memory Pre-test on CPIDR Score

Working Memory	*R Squared*	*F*	*Sig.*	*Task*	*B*	*SE B*	*β*	*Sig.*
Temporal Working Memory	.057	1.024	.370	TSWM	.062	.044	.241	.166
				TWM	-.003	.031	-.016	.928
Spatial Working Memory	.050	.904	.414	TSWM	.037	.031	.213	.246
				SWM	.033	.032	.187	.307

Note: *p <0.1. **p < .05

Effects of Propositional Density on EM

Although a direct relationship has not been established, certain characteristics such as contextual richness have been shown to be shared between both EM (Uncapher et al., 2006; Morcom et al., 2007) and propositional density (Kemper & Sumner, 2001), suggesting a potential relationship between these two abilities. This raises the question of whether propositional density is able to provide additional context for EM, which would then promote encoding and retrieval. We examined this relationship across several tests, in which we predicted that higher propositional density scores would be associated with higher levels of EM.

Effects across training days. First we examined how propositional density was affected throughout the EM training procedure. Based on the potential relationship between EM and propositional density, we predicted participants would improve propositional density scores across EM training days, as participants got better at increasing the amount of information packed into each story. To test this, participant's CPIDR scores were averaged over each day of training. In order to detect the overall differences between these means, a repeated measures ANOVA was conducted with day of training as the within factor. The results failed the test of sphericity, so Greenhouse-Geisser correction was used to test the main effect of day $F(2.229,89.171)= 3.146$, $p = .032$. Results showed a significant quadratic effect for day of CPIDR scores across days of training $F(1,40)= 5.996$, $p = .019$ (Table 11). Additionally, post-hoc comparisons were conducted using the Bonferroni correction. Results showed a significant difference between day 2 and day

4 (*MD*=.016, p = .048) (Fig. 6). Average CPIDR scores on the first day (*M*=.4739, *SD*=.0419) decreased on the second day (*M*=.4653, *SD*=.0429), and then increased on the third (*M*=.4720, *SD*=.0427) and fourth day (*M*=.4808, *SD*=.0429).

Table 11

Repeated Measures ANOVA of CPIDR Score.

Effect of Condition	*Value*	*df*	*F*	*Sig.*	η^2	*Observed Power*
Wilks' Lambda	.770	38	3.789	.018**	.230	.773
Greenhouse-Geisser		89.171	3.146	.032**	.079	.661
Linear		40	2.271	.140	.130	.313
Quadratic		40	5.996	.019**	.032	.666

Note: *p <0.1. **p < .05

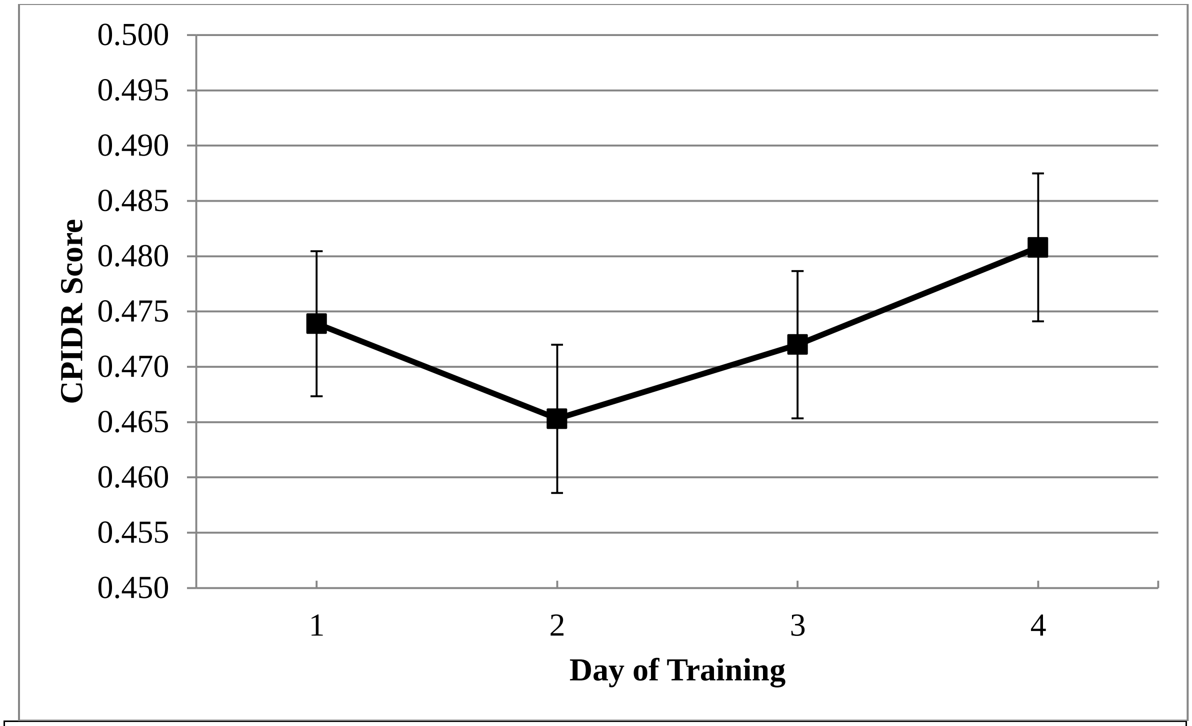

*Figure 6.*CPIDR (propositional density) score across days of training. Error bars are the standard error of the mean.

Effects on EM accuracy during training. Next we examined how propositional density was related to EM recall during the training procedure. Based on previous indirect evidence of a relationship between EM and propositional density (Uncapher et al., 2006; Morcom et al., 2007; Kemper & Sumner, 2001), we predicted higher propositional density scores would positively correlate with higher EM accuracy scores during training day recall. This would be due to the stories during the training task being more context-rich, and thus, more memorable. A Pearson's correlation was run between the average CPIDR scores of participant's EM training day stories and their EM accuracy during each recall period (0, 24, 48, and 72 hours). There was a positive correlation between total average CPIDR scores and delayed recall accuracy during training at 48 hours, r = .389,*p* = .012(Fig. 8), 72 hours (r = .424, *p* = .006)(Fig. 9), and a trending correlation for delayed recall accuracy during training at 24 hours (r = .292, *p* = .064)(Fig. 7)**.** However, there was no significant correlation between average CPIDR scores to immediate recall accuracy during training on same day.

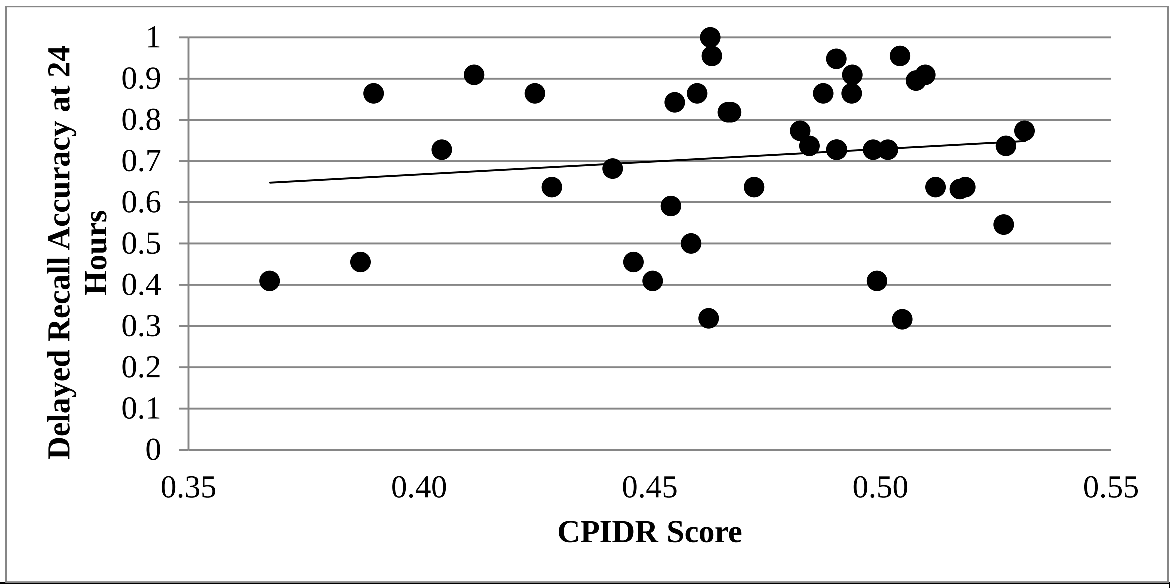

Figure 7. Correlation between CPIDR (propositional density) score and delayed recall accuracy during training task at 24 hours. r = .292, *p* = .064*.
Note: **p* <.01. ***p* <.05

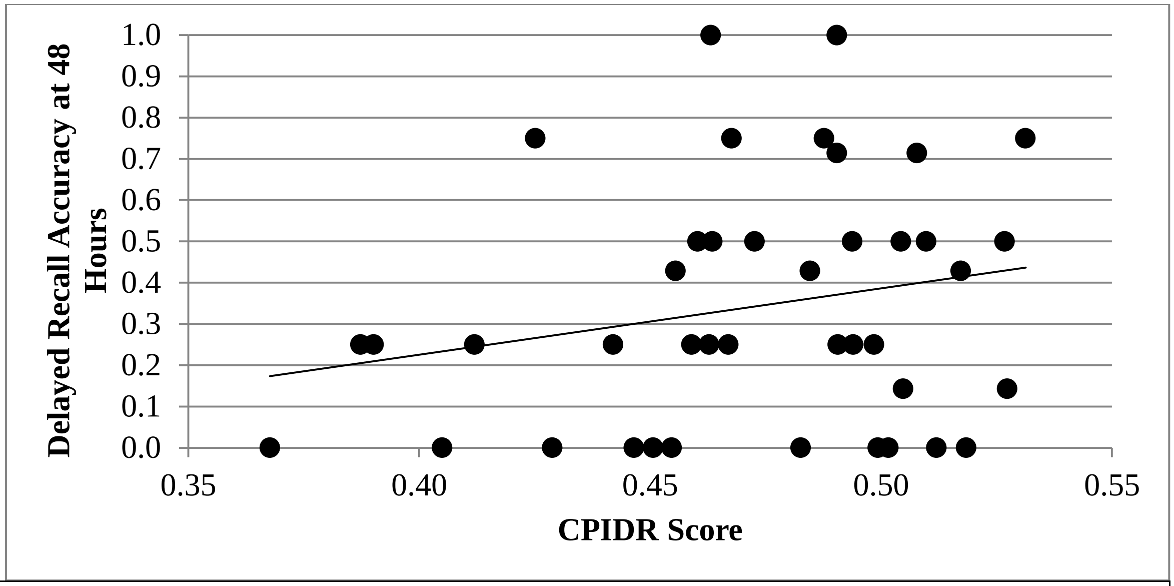

*Figure 8.*Correlation between CPIDR (propositional density) score and delayed recall accuracy during training task at 48 hours. r = .389, p = .012**.
Note: *p <.01. **p <.05

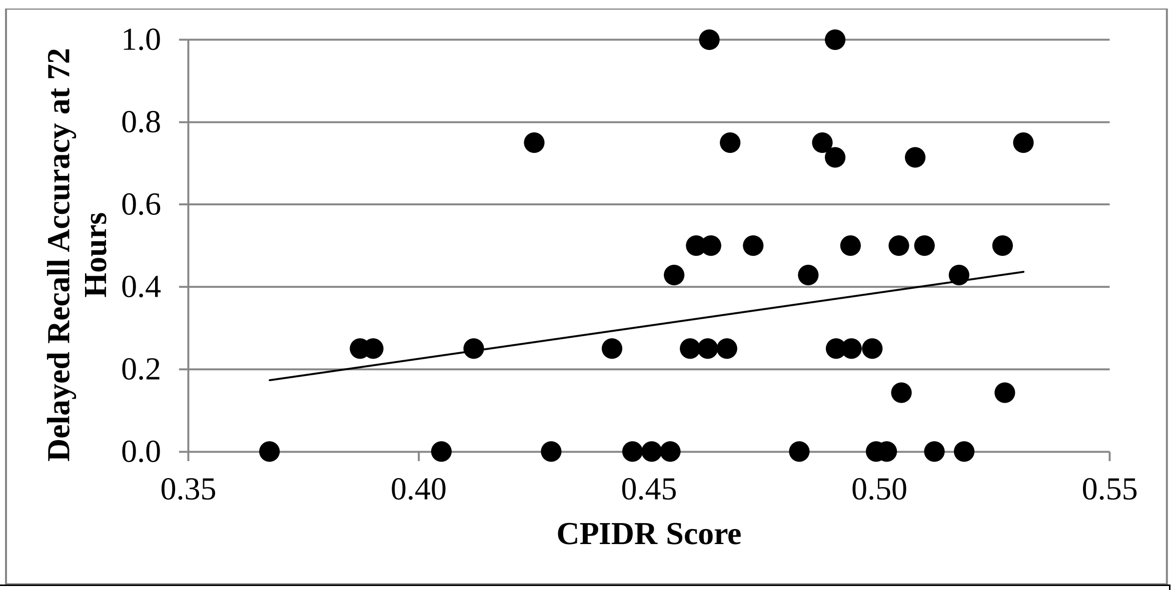

*Figure 9.*Correlation between CPIDR (propositional density) score and delayed recall accuracy during training task at 72 hours. r = .424, p = .006**.
Note: *p <.01. **p <.05

Effects of EM post-test scores. Next we examined the relationship between propositional density and EM post-test scores. Based on the hypothesized relationship between EM and propositional density, we predicted participants with higher average propositional density scores would be associated with greater EM post-test scores. This would be due to participants with high propositional density having improved strategies for EM encoding and retrieval. To test this, a linear regression was run to predict EM post-test score from CPIDR score. Total average of CPIDR scores was unable to significantly account for the variance in EM in either the WMSi task, $F(1,39) = .455$, $p = .504$, nor the WMSd task, $F(1,39) = .501$, $p = .483$(Table 12).

Table 12

Regression of CPIDR Score on WMSi/d Post-Test

Task	*R Squared*	*F*	*Sig.*	*B*	*SE B*	*β*	*Sig.*
WMSi	.012	.455	.504	-.460	.682	-.110	.504
WMSd	.013	.501	.483	.536	.757	.116	.483

Note: *p <0.1. **p < .05

Discussion

Effects of EM training on EM formation and retrieval

Based on previous evidence of structural changes in human brain associated with EM training in humans (Engvig et al., 2010; Valenzuela et al., 2003; Nyberg et al., 2003) and evidence that EM is enhanced through cognitive training (Mahncke et al., 2006; Buschkuehl et al., 2008; Jennings & Jacoby, 2003), we hypothesized that EM training would (a) rapidly improve EM performance and (b) would transfer to Gf. In partial support of the first hypothesis, we found indirect evidence that EM training was effective in improving EM formation and retrieval during both the WMS immediate and delayed task, that the EM training task was able to predict both the WMS immediate and delayed test performance, and that EM accuracy increased across training days. Additionally, there was a quadratic effect that may have been caused by the participants needing to learn to encode novel information under timed pressure. However, we did not find evidence of transfer of EM training to Gf. Although both experimental and control groups improved in Gf (measured in RAPM and EPT) from pre- to post-training the repeated measures showed only marginally significant effects. Although prior studies have examined the effects of EM training, only a few have examined its effects on EM performance (Brigham & Pressley, 1988; Verhaeghen, et al., 1992; Lustig, et al., 2009). Our findings of benefits of EM training by repeated encoding and retrieval is a novel approach and notable for finding EM training can improve EM performance. This finding suggests that repeated taxation of the MTL structures during EM training may indeed be enough to elicit EM improvement.

Effects of baseline WM performance on EM training

Relatively little is known about the role WM plays in the formation and retrieval of EM (Ranganath, 2005). However, evidence shows that WM is related to measures of long-term memory (Mogle, Lovett, Stawski, & Sliwinski, 2008; Unsworth, Brewer, & Spillers, 2009), suggesting a potential relationship between these two types of memory. Based on this evidence we hypothesized that baseline WM would influence benefits of EM training. A growing body of evidence shows differences in brain mediation between temporal and spatial information maintenance (Hsieh et al., 2011), and these regions relate to EM (Hsieh et al., 2014). This suggests that temporal and spatial WM may influence EM training and performance in different ways (Hsieh et al., 2011). To examine this we measured both temporal and spatial WM.

Consistent with that evidence, we found that baseline temporal WM was able to account for variance seen in immediate recall accuracy during training on same day and in delayed recall accuracy during training at 24 hours after initial encoding. That baseline temporal WM performance could not account for delayed recall accuracy during training at 48 and 72 hours after initial encoding, suggests that temporal WM ability may play more of a role in the initial stages EM training compared to later stages. Additionally, spatial measures of WM were able to significantly account for variance seen at immediate recall accuracy during training on same day, and showed trending effects at delayed recall accuracy during training at 24 and 72 hours after initial encoding. That baseline WM performance could account for immediate recall accuracy during training on same day and delayed recall accuracy during training at 24 and 72 hours after initial encoding, suggests that WM ability may play a role throughout EM training. Regarding previous evidence showing differential effects of temporal and spatial WM based on the EM training procedure (Hsieh et al., 2011), both measures of WM were able to account for changes in EM training. Although the specific relationship WM has with EM remains unclear, this is the first study to examine the effects of WM on EM training. We found novel evidence that WM ability influenced EM training performance, providing evidence that WM is indeed related to the formation and retrieval of EM.

Effects of propositional density on EM formation, EM training, EM performance, and WM performance

Although little previous research has directly explored the relationship between propositional density and EM, evidence suggests there may be a link. Both propositional density and EM are associated with contextual richness (Kemper & Sumner, 2001). Based on this evidence we hypothesized that higher propositional density scores would be associated with higher levels of EM. Likewise, although research has not directly linked propositional density and WM, characteristics of propositional density may be able to be explained by WM. Specifically, having better WM may led to better encoding and better processing efficiency, a characteristic of propositional density (Kemper & Sumner, 2001). Based on this evidence, we hypothesized that baseline WM would be able to account for propositional density scores across training days. Our results were mixed. In contrast to our predictions, WM was unable to account for propositional density scores during the training task. Additionally, propositional density scores did not predict EM post-test scores. However, in partial support of the third hypothesis, we found indirect, correlational evidence of a relation between propositional density of the stories created to remember the images and later EM recall. Positive correlations were found between propositional density scores and EM recall at 24, 48, and 72 hours after initial encoding indicating there may be some association between propositional density and delayed recall. More interestingly was a quadratic effect in propositional density scores across training days, with participants showing a significant improvement in propositional density scores across day 2 and day 4 of training, showing that EM training may play a role in propositional density improvement. The reason for this quadratic effect is not certain. We speculate it may be related to the amount of effort participants exerted. Although results were mixed, there is enough evidence to support future studies investigating possible links between propositional density and EM.

Conclusions

Our strongest findings were (a) that EM training did improve EM performance in a manner that increased over days and (b) that WM ability influenced EM training performance. These findings have potential ramifications for future efforts to improve EM in healthy people and in people with difficulty forming new EM due to neuropathology.

Limitations

Because this study was part of a larger study focused on the epigenetic effects of episodic memory training, there were several limitations. This study was not initially designed to examine propositional density. Prior studies examining propositional density have focused on autobiographical writings written in young adulthood, involving retrieval of the participant's EM (Snowdon, 1996). In our study the compositions were part of the EM training task were composed during EM formation, as opposed to EM retrieval. In addition, in contrast to prior studies which examined longer autobiographical writings (Snowdon, 1996), our analyzed writings tended to be very short (1 to 5 sentences). These shorter stories may not be well-suited to the CPIDR software used to calculate propositional density.

Finally, there were some problems with the measures of Gf. Specifically, the BOMAT was not added as part of the protocol until part way through the study. Additionally, due to experimenter error the completion time for the RAPM was not recorded initially. This meant that Gf measures were based only on RAPM accuracy and not RAPM time.

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Biography

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