Learning and Memory Improvement: Evidence from Current Research and Neurofeedback Applications

Hafeez Ullah Amin[a*], *Aamir Saeed Malik*[b]

[a]*Centre for Intelligent Signal and Imaging Research (CISIR), Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia*
[b]*CTO, brain9D, Adelaide, South Australia*
Email: [a]hafeezullah.amin@utp.edu.my, [b]aamirdip@gmail.com

Abstract

Learning and memory are two related, but distinct, fundamental cognitive processes. Both of these are continuous processes over the life span. In the current article, we provide a comprehensive review of the extant literature that has focused on various factors that influence the human brain processes for learning and memory. We review several factors that have been reported as directly or indirectly influence the learning and memory processes, such as sleep, emotion, exercise, attention, intelligence, testing, rehearsal, and technology. We also examine the literature on ways to enhance cognitive abilities, including neurofeedback, improve learning and memory capabilities**.** We conclude with a discussion of the gaps in the literature and suggestions for future research in the field.

Keywords: Learning & memory, neurofeedback (NFB), sleep, attention, stress, emotion, intelligence, testing & rehearsal, and technology.

ARTICLE INFO		* *Corresponding author.*
RECEIVED	September 30, 2019	Email: hafeezullahamin@gmail.com
REVIEWED	October 24, 2019	
ACCEPTED	November 19, 2019	

1. Introduction

Learning, memory, and intelligence are the three main cognitive processes, which are somehow interdependent but different processes. In daily life, learning and memorization are continuous processes. The ability to learn and remember about people, places, things, and working procedures is encountered in routine life. It is a primary characteristic of humans' cognition, which guides their behaviour. Learning is a process to develop new skills, knowledge, and experience; while memory is the ability to retain learned experience and reuse later. Intelligence reflects the speed of information processing, reasoning skills and the ability of problem-solving. All three cognitive processes play an important role in human life. However, memory ability is very critical and provides backup to both learning and information processing. For example, the use of language to convey thoughts via processing the known letters and sounds in a combined manner to make words is based on memory. Without memory, nothing could be learned from experience. Motor skills, language ability, reasoning, decision making, fast response, sense of personal identity, emotion and problem solving are impossible to achieve without memory ability. This article aims to give a comprehensive overview of factors that influence learning and memory abilities, taking evidence from recent physiological and psychological studies. The following section provides a detailed review of all factors that influences learning and memory processes.

2. Literature Review

In previous studies, there are many factors, including intelligence, attention, rehearsal, testing/retrieval, sleep, exercise, nutrition, and multimedia tools, reported as factors, which influence performance of learning and memory and help us to retain more information and minimize forgetting. In this section, a number of common factors are discussed.

2.1 Sleep

Sleep is a critical factor in memory, especially for memory consolidation. This has been well-established over the last several decades for procedural and declarative memory (Ekstrand, Barrett, West, & Maier, 1977). A recent study examined sleep's impact on memory for school performance (semantic memory) in adults (Potkin & Bunney, 2012). An experiment was performed with male and female healthy school students. The results showed an improvement of 20.6% in memory as recorded by the number of correct responses in the paired-associate test following sleep. Bell et al., (Bell, Kawadri, Simone, & Wiseheart, 2014) investigated the sleep effect on memory with 12 hours and 24 hours of retention duration and reported improvement in memory due to sleep. The neuronal mechanism of sleep impact on memorization with neuroimaging techniques was reviewed by Frank and Benington (Frank & Benington, 2006). A few studies indicate that sleep modulating slow brain waves favored memory consolidation, (e.g. Marshall, Helgadóttir, Mölle, & Born, 2006) and (Maquet, 2001). In short, the brain creates new neuronal connections during the learning process, and these connections are then consolidated in the sleep process, resulting in better memorization.

2.2 Attention

Attention and memory are interdependent processes. New memory formation without proper attention is not possible. The reason is that the capacity of human sensory memory and short-term storage is minimal; while the surroundings provide plenty of information that is being received through the senses. Thus, the memory needs to encode only important information (information of interest). Attention determines what should be encoded (Chun & Turk-Browne, 2007). It is evident in modern psychology that attention helps to improve memory, but the detail of this enhancement in relation to neuroscience is still debatable. However, this is a common observation and also experimentally proven that attending to (focusing on) a fact/event will increase the likelihood of memorization. The acceptable view among the memory experts of this relation between attention and memory is that focusing on or attending to a fact or event means allocation of processing resources of the brain for specific task (Awh, Vogel, & Oh, 2006; Chun & Turk-Browne, 2007; Theeuwes, Kramer, & Irwin, 2011). This way, attention is involved in selecting the information of interest to be remembered and preventing other sensory information from encoding. As a result, the relevant information is remembered in a better way. In the case of competition between stimuli (sensory information) in the environment, selective attention is useful (Uncapher & Rugg, 2009).

2.3 Rehearsal

Rehearsal is also an influential factor in memory. The functions of rehearsal are to maintain information active in working memory and to create new memory traces for long-term retention (Naveh-Benjamin & Jonides, 1984). Based on these functions, rehearsal is divided into two, i.e., maintenance rehearsal and elaborative rehearsal (Craik & Watkins, 1973; Dark & Loftus, 1976). The former is just repetition of stimulus again and again without knowing the semantic detail and only useful for rote learning; while the latter deals with the stimuli (sensory information) in a meaningful and elaborative way to deeply process and remember it. The elaborative rehearsal is more useful for memory and longer retention duration.

2.4 Emotion

Emotion is another factor which is not only a product of the information processing of the brain but also influences the learning and memory processes directly (Chai M Tyng, Amin, Saad, & Malik, 2017). Recent studies demonstrated that emotional material is typically better to memorize than non-emotional or inert material. A positive emotional component may be added to the learning contents while students undergo new information to improve subsequent memory (Schwabe, Bohringer, Chatterjee, & Schachinger, 2008; Zoladz et al., 2011). For example, movie clips may be used, which will place the learning material into emotional context as well as attract the focus of the students toward the learning material (Chai Meei Tyng et al., 2019). It is reported by (Tendler & Wagner, 2015) that when the emotion is social and positive, our brain tells the different areas to work according to a specific communication protocol. When a different emotion is involved, say a negative emotion of fear, then the brain instructs the same areas to adopt a different communication protocol. Nevertheless, further investigation is needed to explore the reasons that we use different communication networks with different emotions.

2.5 Stress

Previous studies identified stress and the neurotransmitters released during and after a stressful episode as a critical modulator of human learning and memory abilities, especially in educational contexts(Joëls, Pu, Wiegert, Oitzl, & Krugers, 2006) (Schwabe, Joëls, Roozendaal, Wolf, & Oitzl, 2012). In education, it is common to face stressful events both for students and teachers, for example, exams, presentations, evaluations, deadlines, and achieving high performance create high pressure to perform.

Recent studies summarized by Vogel and Schwabe in 2016, stated that studies in rodents suggest that stress induces a qualitative shift in the systems guiding learning and memory retrieval from a hippocampus-dependent memory system towards a habit-like memory system based on the striatum (Vogel & Schwabe, 2016). Further, stress influenced the hippocampus-dependent memory negatively, while having no effects on habit-learning in humans.

2.6 Intelligence

Cognitive ability, or general intelligence, has been commonly used to help predict an individual's capacity and the ability for academic learning (Koczwara et al., 2012; Rindermann & Neubauer, 2004; Wang & Hsieh, 2013). The assessment of general intelligence involves the use of deliberate mental operations that are employed to solve novel problems that cannot be accomplished by simple memorization (Primi, Ferrão, & Almeida, 2010). Furthermore, several cognitive psychological studies have associated general intelligence with learning ability as predictors of an individual's learning capacity and ability (Amin, Malik, Kamel, Chooi, & Hussain, 2015; Deary, Strand, Smith, & Fernandes, 2007; Rindermann & Neubauer, 2004; van den Bos, Crone, & Güroğlu, 2012; Wang & Hsieh, 2013) and results from such studies have potential implications for learning practices. For example, it has been demonstrated that executive functions and general intelligence are highly associated with learning capabilities (van den Bos et al., 2012). However, subjective differences do exist that discriminate between human learning and memory performances. These differences may be due to a person's ability to (i) perceive complex concepts; (ii) competently adjust to the environment; and (iii) integrate different forms of intellectual and thinking processes. Nevertheless, on different occasions and in different domains, intellectual performances can and do differ (Neisser et al., 1996).

2.7 Testing

Testing or retrieval practice is the process in which the studied items or stored memory are recollected. Unlike rehearsal in which the information is studied, again and again, the testing process retrieves the learned information. The correct retrieval enhances long-term retention more than the additional study of the information or material. Testing is not just an assessment tool for learning but also improving long-term retention. Karpicke and Roediger first studied the testing effect in comparison with a rehearsal for long-term retention (Karpicke & Roediger, 2007, 2008; Roediger & Butler, 2011). The authors conducted two experiments, in the first experiment, the retention durations were five minutes, two days and one week. The experimental conditions were 'study-study' and 'study-test'. The participants studied educationally relevant passages and then either restudy or take a recall test. The findings (see Figure 1.2) suggested that rehearsal improves memory for short retention duration such as five minutes; however, for long-term retention, the participants that took recall test after studying the material rather than restudy, recalled more than the participants who restudy the material instead of test.

In the second experiment, the findings were more interesting, where they observed the participants with three experimental conditions, 'SSSS', 'SSST' and 'STTT' (see Figure 1.3). The S stands for 'study' and T represents 'Test'. In short-term retention, the participants in the group of 'SSSS' condition recalled more than the rest of the two conditions 'SSST' and 'STTT' in the memory test. However, the recalled performance was reversed for long-term retention, i.e., the group with 'STTT' condition showed the highest recall performance than the rest of the two conditions 'SSSS' and 'SSST'. The testing effects have been investigated by many researchers on different aspects of learning and memory, such as Danial et al., (McDaniel, Anderson, Derbish, & Morrisette, 2007) reported testing the effect in classroom and Chan and McDermott (Chan & McDermott, 2007) examined testing effect for recognition memory. However, the work of Karpicke and Roediger demonstrated a substantial impact of testing on long-term memory.

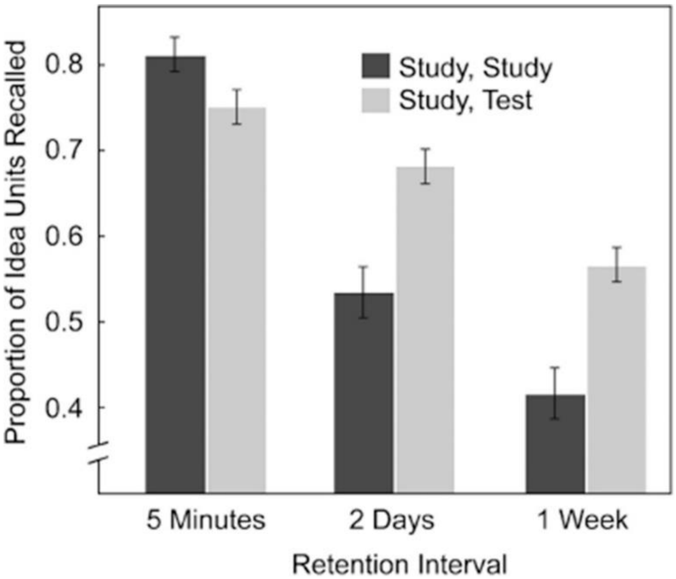

Figure 1: Proportion of memory recall in three different retention durations for rehearsal and testing effects (Roediger & Karpicke, 2006)

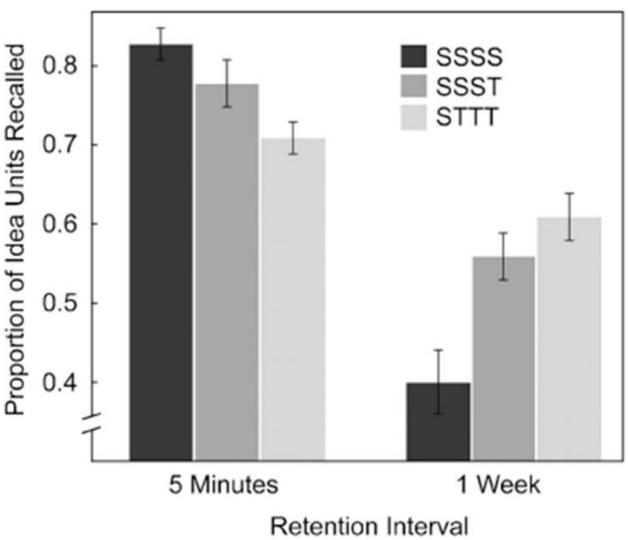

Figure 2: Comparison of three experimental conditions for memory retrieval with two types of retention intervals (Roediger & Karpicke, 2006)

2.8 Exercise

Animal studies provided evidence that regular exercise for the long-term potentiates learning and memory in young adults and old age (Asl, Sheikhzade, Torchi, Roshangar, & Khamnei, 2008; Snigdha, de Rivera, Milgram, & Cotman, 2014). However, human studies provided clues that exercise promotes human memory in old age especially in age-related memory losses (Berchtold, Castello, & Cotman, 2010; Hillman, Erickson, & Kramer, 2008; Roig, Nordbrandt, Geertsen, & Nielsen, 2013). Evidence from sports studies suggested that exercise increases the cerebral blood flow for the short-term and thus improves the availability of oxygen, glucose, and nutrients (Ogoh & Ainslie, 2009; Querido & Sheel, 2007). This may be the reason for the brain to perform better with cognitive functions. From neuroimaging studies, it is reported that exercise improves the size of the hippocampus, which is a critical and necessary brain organ for creating a memory (Erickson et al., 2011). The hippocampus shrinks in late adulthood, causing severe losses of memory and memory impairments (dementia). Thus, exercise can regulate the brain tissues in the hippocampus to prevent tissues from shrinking and delay memory losses or maintain memory functions.

2.9 Nutrition

An important factor in mental fitness is nutrition. Several research studies examined how food relates to brain functions, including memory and cognition. Previously, fats were considered inadequate for heart regulation, but in fact, it is also bad for brain functions including memory (Gómez-Pinilla, 2008; Gu, Nieves, Stern, Luchsinger, & Scarmeas, 2010). A recent study investigated dietary fat types on cognitive functions in healthy elders (Okereke et al., 2012) and reported that higher intake of saturated fatty acids associated with reduced cognitive and verbal memory. In addition, iron deficiency (ID) is another common nutrient deficiency that affects cognitive functions, including speed of processing, learning, and memory. It has been reported that early ID alters the structure, intracellular signaling pathways and electrophysiology of the developing hippocampus organs (Fretham, Carlson, & Georgieff, 2011). Hence, a balanced diet is essential not only for physical fitness but also for better cognitive functions.

2.10 Technology

Multimedia tools consist of auditory information as well as visual information, such as spoken words and pictures. In multimedia learning, the learner builds a mental representation of a concept from both visual and auditory information presented simultaneously (Richard E. Mayer, 2002a). Allan Paivio first brought the idea of multimedia processing in 1971 with dual coding theory (Paivio, 1971). According to this theory, "the human brain deals the verbal and non-verbal information in separate interrelated systems". Later, researchers worked on the learning process and explored the modality effect of materials presentation, known as the modality principle. The modality principle postulated that the integration of visual (pictorial) and auditory (narration) materials provided better memory retention and information transfer compared to a combination of written (textual) and pictorial material (Richard E Mayer, 2002). This principle, based on the working memory concept of limited capacity, suggests that combined presentation of animation and narration allowed the learners to efficiently coordinate between the phonological loop and visuospatial sketch pad instead of burdening one channel of information processing (Richard E. Mayer, 2002b). Thus, the combined presentation of visual and auditory information helps the brain to learn quickly and efficiently.

In technology, stereoscopic 3D (S3D) displays, and virtual reality are relatively new. Since the year 2009, 3D technology has become famous and resulted in evolving the entertainment market, including movies, games, TVs, cameras, and smartphones. However, in the last few years, 3D technology started growing into a more serious domain such as education (Malik, Amin, et al., 2015; Malik, Amin, Kamel, Chooi, & Hussain, 2014). The existing research work is focused on the technical aspects of 3D technology including the development of 3D displays (Downing, Hesselink, Ralston, & Macfarlane, 1996; Redert et al., 2006), conversion of 2D images into 3D images (Harman, Flack, Fox, & Dowley, 2002; Tam & Zhang, 2006), human factor including discomfort (Tam, Speranza, Yano, Shimono, & Ono, 2011), cognitive and visual fatigue (Li, Seo, Kham, & Lee, 2008; Mun, Park, Park, & Whang, 2012), and quality of the 3D movies and games (Kalva, Christodoulou, Mayron, Marques, & Furht, 2006; Leon, Kalva, & Furht, 2008; Merkle, Müller, & Wiegand, 2010). A behavioral study on 3D technology for education is available, conducted by Bamford in 2011 (Bamford, 2011), which reported that 86% of the students in 3D class improved their test score from pre-test to the post-test as compared to 52% of the students who improved in the 2D class. Individual performance was also improved in 3D class than 2D class, i.e., an average of 17% improvement was recorded in 3D class as compared to only 8% improvement in 2D class. This study was conducted on a large sample size of 740 students over 15 schools in seven countries in Europe. However, the reasons for the improvement of the students in 3D classes were not reported and remained unknown, because the study was a behavioral study which is based on questionnaires or paper-based tests. The possible effects of the 3D display during learning and memory may be of attracting more viewers' attention and helps hasten retrieval of information from long-term storage (Amin, 2017). However, the S3D display technology needs to improve the visual comfort to the viewers, as there are still complaints of visual discomfort and fatigues (Malik, Khairuddin, et al., 2015). Also, the design of the S3D based learning materials should follow the cognitive theory (Richard E Mayer, 2002) to ensure the cognitive load is not overloading the working memory during viewing the learning materials (Mazher, Aziz, Malik, & Amin, 2017).

3. Neurofeedback as Intervention for enhancement of learning and memory

Neurofeedback (NFB) is a method to self-regulate one's brain activity to modulate the underlying neural mechanisms of cognition and behavior directly. It is used as a therapeutic tool and provides new avenues for researchers and clinicians for cognitive enhancement in healthy human participants. The areas of NFB application include NFB as a therapeutic tool for ADHD, epilepsy, and motor imagery, NFB as peak performance training for cognitive enhancement, and NFB as an experimental method, for example, the relation of specific oscillation with cognitive functions. Thus, NFB can be used to enhance cognitive functions and provide peak performance using well established NFB protocols. Although the protocols of NFB are debatable, specific protocols are quite well established, for example, peak alpha for information processing and intelligence (Posthuma, Neale, Boomsma, & De Geus, 2001). Specific NFB protocols are in practice for the enhancement of memory performance. For example, Wang and Hsieh (Wang & Hsieh, 2013) investigated the effectiveness of frontal-midline theta activity up training protocol for attention and working memory performance for older and young participants. They reported that frontal-midline theta up training protocol enhanced attention and working memory and theta activity for healthy aging adults in resting state. Also, younger participants were also found to benefit from the protocol as their executive function was improved. Rostami et al., (Rostami et al., 2017) evaluated the effect of NFB therapy on continuous attention and short-term memory of clients with moderate traumatic brain injury adopting a randomized controlled clinical trial. Their results could not achieve a significant improvement between intervention and control groups. However, they have reported a small sample size in the experiment, which could be the reason for obtaining non-significant improvement. Haddadi et al., (Haddadi, Rostami, Moradi, & Pouladi, 2011) explored the effect of NFB on memory and learning in patients with cognitive impairment. They have incorporated training to increase beta waves (15-18Hz) and decease theta waves (3-7Hz) at T3 and F3. Also, SMR training was used in Cz to decrease the seizure attacks. The findings evident changes in increased beta waves and decreased theta activity. Such studies indicated that NFB therapy should be considered when designing studies and treatment for rehabilitation of patients with cognitive impairment, students having learning disabilities, and individuals willing to enhance their cognitive performance.

4. Discussion and Concluding Remarks

Factors such as attention, rehearsal, testing, and sleep, which influence learning and memory, as reported in the literature, are all well studied in behavioral research for many decades. A few factors, such as emotion, stress, and technology, are relatively new in learning and memory research and need further in-depth investigations to explore the underlying mechanisms. The following Table 1 summarizes the current research studies on different factors related to learning & memory along with NFB to come up with possible research gaps for future investigations.

Table 1. Gaps of Knowledge in current research of Learning and Memory factors

Ref.	Factors	Studied	Remarks
(Berner, Schabus, Wienerroither, & Klimesch, 2006)	Sleep	Sleep spindles for overnight memory consolidation, and sigma (11.6 to 16 Hz) NFB training on immediate sleep spindle and overnight memory	The results reported there was a significant positive correlation between spindle activity during sleep in the first half night and overall declarative memory performance.
(Schwabe et al., 2012)	Stress	Current trends of stress effects on memory are discussed along with popular models of how stress hormones alter memory processes.	The study concluded that depending on the timing of the stress exposure, stress might positively alter the hippocampus-dependent memory. However, it needs further attention to study how stress shapes memory to guide individuals for such circumstances in the future.
(Chai Meei Tyng et al., 2019)	Emotion	Colours' effects with EEG networks on emotion for learning & memory are investigated.	The study indicated that coloured multimedia learning contents induced positive emotional experiences during learning, which increased the motivation to learn and memorize. The study only tested 45 young subjects.
(Keizer, Verschoor, Verment, & Hommel, 2010)	Intelligence	For improvement in intelligence, NFB is applied to change the power of EEG gamma-band	The results suggested that alterations in EEG gamma-band power influenced intellectual ability.
(Escolano, Aguilar, & Minguez, 2011)	Working Memory	EEG upper-alpha activity is trained for improving working memory	The results showed that significant improvements in working memory are produced. The use of NFB on working memory training towards supporting the long-term encoding and retention can be useful training.
(Norris, Creem, Hendler, & Kober, 2018)	Attention	A brief 10 minutes of audio meditation is investigated on the allocation of attentional resources with event-related potential tasks.	The findings suggested that brief meditation impacts attention. However, the use of NFB may better influence the brain waves responsible for attention as compared to indirectly altering with audiotape meditation.
(Lecomte & Juhel, 2011)	NFB	The use of NFB is reported for memory performance on old aged participants (over 65 years)	The study did not report encouraging results of NFB on memory; the reason may be that the authors used only 4 NFB training sessions. However, more training sessions on healthy young participants may improve memory performance.
(Reiner, Rozengurt, & Barnea, 2014)		Theta and beta NFB training in comparison with sleep	The study reported that theta NFB training gives superior results in memory consolidation than beta training and night sleep.

In the view of many recent research studies, evidence suggests that various psychological and physiological factors are involved in the acquisition of new information and the consolidation of the acquired information into memories. Although open questions and debate remain, the overall evidence suggests that certain factors, such as sleep, attention, technology, emotion, testing, stress and rehearsal are playing a critical role in learning and memory processes. Future studies may consider the use of NFB for enhancement of learning and memory for healthy human subjects and especially for those who have learning disabilities.

References

Amin, H. U. (2017). *Semantic long-term memory: assessment and effects of stereoscopic 3D educational contents using EEG signals.* (Ph.D. Research), University Teknologi PETRONAS, Malaysia. Utpedia database.

Amin, H. U., Malik, A. S., Kamel, N., Chooi, W.-T., & Hussain, M. (2015). P300 correlates with learning & memory abilities and fluid intelligence. *Journal of NeuroEngineering and Rehabilitation, 12*(1), 87. doi: 10.1186/s12984-015-0077-6

Asl, N. A., Sheikhzade, F., Torchi, M., Roshangar, L., & Khamnei, S. (2008). Long-term regular exercise promotes memory and learning in young but not in older rats. *Pathophysiology, 15*(1), 9-12. doi: 10.1016/j.pathophys.2007.10.002

Awh, E., Vogel, E., & Oh, S.-H. (2006). Interactions between attention and working memory. *Neuroscience, 139*(1), 201-208.

Bamford, A. (2011). The 3D in Education White Paper *International Research Agency*.

Bell, M. C., Kawadri, N., Simone, P. M., & Wiseheart, M. (2014). Long-term memory, sleep, and the spacing effect. *Memory, 22*(3), 276-283.

Berchtold, N. C., Castello, N., & Cotman, C. W. (2010). Exercise and time-dependent benefits to learning and memory. *Neuroscience, 167*(3), 588-597.

Berner, I., Schabus, M., Wienerroither, T., & Klimesch, W. (2006). The significance of sigma neurofeedback training on sleep spindles and aspects of declarative memory. *Applied Psychophysiology and Biofeedback, 31*(2), 97.

Chan, J. C., & McDermott, K. B. (2007). The testing effect in recognition memory: a dual process account. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(2), 431.

Chun, M. M., & Turk-Browne, N. B. (2007). Interactions between attention and memory. *Current Opinion in Neurobiology, 17*(2), 177-184.

Craik, F. I. M., & Watkins, M. J. (1973). The role of rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior, 12*(6), 599-607. doi: http://dx.doi.org/10.1016/S0022-5371(73)80039-8

Dark, V. J., & Loftus, G. R. (1976). The role of rehearsal in long-term memory performance. *Journal of Verbal Learning and Verbal Behavior, 15*(4), 479-490.

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence, 35*(1), 13-21.

Downing, E., Hesselink, L., Ralston, J., & Macfarlane, R. (1996). A three-color, solid-state, three-dimensional display. *Science, 273*(5279), 1185.

Ekstrand, B. R., Barrett, T. R., West, J. N., & Maier, W. G. (1977). The effect of sleep on human long-term memory. *Neurobiology of sleep and memory*, 419-438.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., . . . Kramer, A. F. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences, 108*(7), 3017-3022. doi: 10.1073/pnas.1015950108

Escolano, C., Aguilar, M., & Minguez, J. (2011). *EEG-based upper alpha neurofeedback training improves working memory performance.* Paper presented at the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

Frank, M. G., & Benington, J. H. (2006). The role of sleep in memory consolidation and brain plasticity: dream or reality? *The Neuroscientist, 12*(6), 477-488.

Fretham, S. J., Carlson, E. S., & Georgieff, M. K. (2011). The role of iron in learning and memory. *Advances in Nutrition: An International Review Journal, 2*(2), 112-121.

Gómez-Pinilla, F. (2008). Brain foods: the effects of nutrients on brain function. *Nature reviews. Neuroscience, 9*(7), 568-578. doi: 10.1038/nrn2421

Gu, Y., Nieves, J. W., Stern, Y., Luchsinger, J. A., & Scarmeas, N. (2010). Food combination and Alzheimer disease risk: a protective diet. *Archives of Neurology, 67*(6), 699-706.

Haddadi, P., Rostami, R., Moradi, A., & Pouladi, F. (2011). Neurofeedback Training to Enhance Learning and Memory in Patients with Cognitive Impairment. *Procedia - Social and Behavioral Sciences, 30*, 608-610. doi: https://doi.org/10.1016/j.sbspro.2011.10.117

Harman, P. V., Flack, J., Fox, S., & Dowley, M. (2002). *Rapid 2D-to-3D conversion.* Paper presented at the Electronic Imaging 2002.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

Joëls, M., Pu, Z., Wiegert, O., Oitzl, M. S., & Krugers, H. J. (2006). Learning under stress: how does it work? *Trends in Cognitive Sciences, 10*(4), 152-158.

Kalva, H., Christodoulou, L., Mayron, L., Marques, O., & Furht, B. (2006). *Challenges and opportunities in video coding for 3D TV.* Paper presented at the 2006 IEEE International Conference on Multimedia and Expo.

Karpicke, J. D., & Roediger, H. L. (2007). Repeated retrieval during learning is the key to long-term retention. *Journal of Memory and Language, 57*(2), 151-162.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*(5865), 966-968.

Keizer, A. W., Verschoor, M., Verment, R. S., & Hommel, B. (2010). The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures. *International Journal of Psychophysiology, 75*(1), 25-32. doi: https://doi.org/10.1016/j.ijpsycho.2009.10.011

Koczwara, A., Patterson, F., Zibarras, L., Kerrin, M., Irish, B., & Wilkinson, M. (2012). Evaluating cognitive ability, knowledge tests and situational judgement tests for postgraduate selection. *Medical Education, 46*(4), 399-408. doi: 10.1111/j.1365-2923.2011.04195.x

Lecomte, G., & Juhel, J. (2011). The effects of neurofeedback training on memory performance in elderly subjects. *Psychology, 2*(08), 846.

Leon, G., Kalva, H., & Furht, B. (2008). *3D video quality evaluation with depth quality variations.* Paper presented at the 2008 3DTV Conference: The True Vision-Capture, Transmission and Display of 3D Video.

Li, H.-C. O., Seo, J., Kham, K., & Lee, S. (2008). *Measurement of 3D visual fatigue using event-related potential (ERP): 3D oddball paradigm.* Paper presented at the 2008 3DTV Conference: The True Vision-Capture, Transmission and Display of 3D Video.

Malik, A. S., Amin, H. U., Badruddin, N., Kamel, N., Ahmad, R. F., & Mumtaz, W. (2015). Evaluation of Stereoscopic 3D Based Educational Contents for Long-Term Memorization. *Annals of Neurology, 78*(S19), S89-S89.

Malik, A. S., Amin, H. U., Kamel, N., Chooi, W.-T., & Hussain, M. (2014). The Effects of 3D Technology on the Brain during Learning and Memory Recall Processes. *Annals of Neurology, 76*(S18).

Malik, A. S., Khairuddin, R. N. H. R., Amin, H. U., Smith, M. L., Kamel, N., Abdullah, J. M., . . . Shim, S. (2015). EEG based evaluation of stereoscopic 3D displays for viewer discomfort. *BioMedical Engineering OnLine, 14*(1), 21.

Maquet, P. (2001). The role of sleep in learning and memory. *Science, 294*(5544), 1048-1052.

Marshall, L., Helgadóttir, H., Mölle, M., & Born, J. (2006). Boosting slow oscillations during sleep potentiates memory. *Nature, 444*(7119), 610-613.

Mayer, R. E. (2002). Cognitive theory and the design of multimedia instruction: an example of the two-way street between cognition and instruction. *New directions for teaching and learning, 2002*(89), 55-71.

Mayer, R. E. (2002a). Multimedia learning *Psychology of Learning and Motivation* (Vol. Volume 41, pp. 85-139): Academic Press.

Mayer, R. E. (2002b). Multimedia learning. *Psychology of Learning and Motivation, 41*, 85-139.

Mazher, M., Aziz, A. A., Malik, A. S., & Amin, H. U. (2017). An EEG-based cognitive load assessment in multimedia learning using feature extraction and partial directed coherence. *IEEE Access, 5*, 14819-14829.

McDaniel, M. A., Anderson, J. L., Derbish, M. H., & Morrisette, N. (2007). Testing the testing effect in the classroom. *European Journal of Cognitive Psychology, 19*(4-5), 494-513.

Merkle, P., Müller, K., & Wiegand, T. (2010). 3 D video: acquisition, coding, and display. *IEEE Transactions on Consumer Electronics, 56*(2), 946-950.

Mun, S., Park, M.-C., Park, S., & Whang, M. (2012). SSVEP and ERP measurement of cognitive fatigue caused by stereoscopic 3D. *Neuroscience Letters, 525*(2), 89-94.

Naveh-Benjamin, M., & Jonides, J. (1984). Cognitive load and maintenance rehearsal. *Journal of Verbal Learning and Verbal Behavior, 23*(4), 494-507.

Neisser, U., Boodoo, G., Bouchard Jr, T. J., Boykin, A. W., Brody, N., Ceci, S. J., . . . Sternberg, R. J. (1996). Intelligence: Knowns and unknowns. *American Psychologist, 51*(2), 77.

Norris, C. J., Creem, D., Hendler, R., & Kober, H. (2018). Brief Mindfulness Meditation Improves Attention in Novices: Evidence From ERPs and Moderation by Neuroticism. *Frontiers in human neuroscience, 12*, 315-315. doi: 10.3389/fnhum.2018.00315

Ogoh, S., & Ainslie, P. N. (2009). Cerebral blood flow during exercise: mechanisms of regulation. *Journal of Applied Physiology, 107*(5), 1370-1380.

Okereke, O. I., Rosner, B. A., Kim, D. H., Kang, J. H., Cook, N. R., Manson, J. E., . . . Grodstein, F. (2012). Dietary fat types and 4-year cognitive change in community-dwelling older women. *Annals of Neurology, 72*(1), 124-134. doi: 10.1002/ana.23593

Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart, and Winston.

Posthuma, D., Neale, M., Boomsma, D., & De Geus, E. (2001). Are smarter brains running faster? Heritability of alpha peak frequency, IQ, and their interrelation. *Behavior Genetics, 31*(6), 567-579.

Potkin, K. T., & Bunney, W. E., Jr. (2012). Sleep Improves Memory: The Effect of Sleep on Long Term Memory in Early Adolescence. *PLoS ONE, 7*(8), e42191. doi: 10.1371/journal.pone.0042191

Primi, R., Ferrão, M. E., & Almeida, L. S. (2010). Fluid intelligence as a predictor of learning: A longitudinal multilevel approach applied to math. *Learning and Individual Differences, 20*(5), 446-451.

Querido, J. S., & Sheel, A. W. (2007). Regulation of cerebral blood flow during exercise. *Sports Medicine, 37*(9), 765-782.

Redert, A., Berretty, R.-P., Varekamp, C., Willemsen, O., Swillens, J., & Driessen, H. (2006). *Philips 3D solutions: From content creation to visualization.* Paper presented at the 3D Data Processing, Visualization, and Transmission, Third International Symposium on.

Reiner, M., Rozengurt, R., & Barnea, A. (2014). Better than sleep: Theta neurofeedback training accelerates memory consolidation. *Biological Psychology, 95*, 45-53. doi: https://doi.org/10.1016/j.biopsycho.2013.10.010

Rindermann, H., & Neubauer, A. (2004). Processing speed, intelligence, creativity, and school performance: Testing of causal hypotheses using structural equation models. *Intelligence, 32*(6), 573-589.

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in cognitive sciences, 15*(1), 20-27.

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning taking memory tests improves long-term retention. *Psychological Science, 17*(3), 249-255.

Roig, M., Nordbrandt, S., Geertsen, S. S., & Nielsen, J. B. (2013). The effects of cardiovascular exercise on human memory: a review with meta-analysis. *Neuroscience and Biobehavioral Reviews, 37*(8), 1645-1666.

Rostami, R., Salamati, P., Yarandi, K. K., Khoshnevisan, A., Saadat, S., Kamali, Z. S., . . . Rahimi-Movaghar, V. (2017). Effects of neurofeedback on the short-term memory and continuous attention of patients with moderate traumatic brain injury: A preliminary randomized controlled clinical trial. *Chinese Journal of Traumatology, 20*(5), 278-282. doi: https://doi.org/10.1016/j.cjtee.2016.11.007

Schwabe, L., Bohringer, A., Chatterjee, M., & Schachinger, H. (2008). Effects of pre-learning stress on memory for neutral, positive and negative words: Different roles of cortisol and autonomic arousal. *Neurobiology of Learning and Memory, 90*(1), 44-53. doi: 10.1016/j.nlm.2008.02.002

Schwabe, L., Joëls, M., Roozendaal, B., Wolf, O. T., & Oitzl, M. S. (2012). Stress effects on memory: an update and integration. *Neuroscience and Biobehavioral Reviews, 36*(7), 1740-1749.

Snigdha, S., de Rivera, C., Milgram, N. W., & Cotman, C. (2014). Exercise enhances memory consolidation in the aging brain. *Frontiers in aging neuroscience, 6*(1), 1-14. doi: 10.3389/fnagi.2014.00003

Tam, W. J., Speranza, F., Yano, S., Shimono, K., & Ono, H. (2011). Stereoscopic 3D-TV: visual comfort. *Broadcasting, IEEE Transactions on, 57*(2), 335-346.

Tam, W. J., & Zhang, L. (2006). *3D-TV content generation: 2D-to-3D conversion.* Paper presented at the 2006 IEEE International Conference on Multimedia and Expo.

Tendler, A., & Wagner, S. (2015). Different types of theta rhythmicity are induced by social and fearful stimuli in a network associated with social memory. *Elife, 4*, e03614.

Theeuwes, J., Kramer, A. F., & Irwin, D. E. (2011). Attention on our mind: The role of spatial attention in visual working memory. *Acta Psychologica, 137*(2), 248-251.

Tyng, C. M., Amin, H. U., Saad, M. N., & Malik, A. S. (2017). The influences of emotion on learning and memory. *Frontiers in psychology, 8*, 1454.

Tyng, C. M., Amin, H. U., Saad, N. M., Abdul Rahman, M., Malik, A. S., & Tang, T. B. (2019). Exploring EEG Effective Connectivity Network in Estimating Influence of Color on Emotion and Memory. *Frontiers in Neuroinformatics, 13*, 66.

Uncapher, M. R., & Rugg, M. D. (2009). Selecting for memory? The influence of selective attention on the mnemonic binding of contextual information. *The journal of neuroscience, 29*(25), 8270-8279.

van den Bos, W., Crone, E. A., & Güroğlu, B. (2012). Brain function during probabilistic learning in relation to IQ and level of education. *Developmental Cognitive Neuroscience, 2*, S78-S89.

Vogel, S., & Schwabe, L. (2016). Learning and memory under stress: implications for the classroom. *npj Science of Learning, 1*, 16011.

Wang, J.-R., & Hsieh, S. (2013). Neurofeedback training improves attention and working memory performance. *Clinical Neurophysiology, 124*(12), 2406-2420. doi: https://doi.org/10.1016/j.clinph.2013.05.020

Zoladz, P. R., Clark, B., Warnecke, A., Smith, L., Tabar, J., & Talbot, J. N. (2011). Pre-learning stress differentially affects long-term memory for emotional words, depending on temporal proximity to the learning experience. *Physiology and Behavior, 103*(5), 467-476.