Evaluating the Influence of Working Memory and Emotion on Human Cognition and Performance

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Introduction to Working Memory

Memory allows humans to access their past to aid in learning and planning for the future. It is made of two distinct, but deeply intertwined parts, forming the complex human cognition process: working memory (an expanded and revised concept originally referred to as short-term memory), and long-term memory (LTM). As Baddeley (1992) explains, "working memory stands at the crossroads between memory, attention, and perception" (pg. 559). Working memory permits humans to understand and visualize their environment, draw from prior knowledge, set goals, and solve problems (Baddeley & Logie, 1999). It allows humans to process tasks that require multiple steps of thinking, leading to the need for information to be temporarily remembered to ultimately make a decision (Miyake & Shah, 1999). Reasoning, comprehension, and learning also rely on working memory (Baddeley, 1992). For example, working memory helps humans compare and choose a car, learn a new language, or visualize how a home remodel could look. As the center of cognition and "the most significant achievement of human mental evolution," working memory is powerful (Goldman-Rakic, 1992, as cited in Miyake & Shaw, 1999, p. 1).

Unlike LTM, working memory is extremely limited in capacity and includes both a storage and processing function, though retrieval from LTM is a vital function (Coolidge & Wynn, 2005). Working memory is the link between bottom-up and top-down processing. Because of the limited capacity, limited duration, and high volatility, the information in working memory can become easily overloaded if the information is not accommodated or assimilated into schemata in LTM. All information from the world that makes it through the pre-processing stages has to pass through working memory before it can be committed to memory; therefore, it is crucial for experience designers to understand the limitations to maximize human performance. When designers understand how to leverage the abilities of working memory, they can design products and services to be easier to learn and adopt. By evaluating prominent theories, this review discusses the importance of working memory and the management of cognitive load on human processing. It then evaluates the role emotion plays alongside working memory in human cognition. The remainder of the review will assess Trello, an online visual organization tool, and its alignment with the capabilities of working memory.

Working Memory Overview and Theories

Working memory evolved from the study of short-term memory where researchers discovered humans with brain injuries can experience isolated cognitive function impairments in either long or short-term memory, making the case for a two-part memory system (Baddeley, 2010). It is understood that Miller et al. (1960) were the first to propose the term working memory, and it has also been used through the years with various meanings in other fields such as education and psychiatry (Baddeley, 2002). Atkinson and Shiffrin (1968) theorized about the concept and referred to working memory as solely a short-term storage function.

Multicomponent Model. With more depth and study, Baddeley and Hitch (1974) proposed working memory also plays a functional role alongside its storage function leading to a multicomponent model. Their original multicomponent model proposed a three-part system including "an attentional control system, the central executive, aided by two short-term storage [slave] systems, one for visual material, the visuospatial sketchpad (VSS), and one for verbal-acoustic material, the phonological loop (PL)" (Baddeley, 2010, p. R137; Coolidge & Wynn, 2005). The central executive is thought to be the most important component since it serves as 'the boss' and directs attention and assigns priority to information (McLeod, 2012). The VSS helps humans keep track of their location with other objects while the PL, made of both the phonological store and the articulatory control process, help humans with speech perception and production (McLeod, 2012). The original model was later updated to include a fourth part, the episodic buffer (Baddeley, 2000). He justifies the episodic buffer, controlled by the central executive, with limited storage capacity, can connect and "bind" information from multiple sources such as the slave systems and LTM into episodes over time. Neurologically, researchers believe "the primary role of the prefrontal cortex is the active maintenance of information [in working memory]… akin to Baddeley's central executive" (O'Reilly et al., 1999, as cited in Coolidge & Wynn, 2005). This model has withstood time and remains influential because of its minimalist approach allowing more development within, but there have been other models proposed with one of the most prominent being Cowan's controlled attention theory (Morey & Cowan, 2005).

Working Memory Limitations

Limited Capacity

Miller (1956) originally indicated that seven, plus or minus two, is the magic number of "meaningful items or chunks of letters, digits, or words" that humans can remember and repeat back. More recently, the prime chunking number has been proven to be smaller and closer to four (Cowan, 2001). Concerning Baddeley's model, these chunks can be thought of as episodes containing bound visual or spatial information. There are arguments for why the limited capacity may be a human flaw, but many theorists agree a limited capacity system is more efficient than an unlimited structure, which would be overwhelming and unworkable (Sweller, 2005). Working memory capacity can also differ amongst humans because individual differences, expertise, and aging will alter the capacity (Cowan, 2001). The limited capacity of working memory restricts the amount of cognitive load (CL) humans can handle and process, it can be visualized as the middle of an hourglass that filters incoming sensory information before entering LTM. Human intelligence stems from stored knowledge, called schemata, in LTM, not from complex chains in working memory that overwhelms the processing system with unfamiliar information (Kirschner, 2002). Schema is processed as a single unit in working memory, no matter how complex or big it is since it has already been learned and stored in LTM. Therefore, cognitive load theory (CLT) rationalizes

that building schema "reduces working memory load" by reducing information to a single, more easily processed "chunk" of information; the load is also reduced when the schemas can be processed unconsciously (Kirschner, 2002, pg. 3).

Cognitive Load Theory. CLT realizes the limited capacity of working memory alongside the unlimited capacity of LTM and encourages promoting "adequate levels of CL" to ensure humans can efficiently process information. CLT includes three types of cognitive load, "working memory load is affected by the inherent nature of the material (intrinsic CL) and by how the material is presented (extraneous and germane CL)" (Kirschner, 2002, pg. 4). Intrinsic CL is the natural complexity of the information, germane CL is caused by putting forth an effort to learn and develop new schema, and extraneous CL is caused by poor information presentation or overload that does not make good use of schemata (Sweller, 2005). Effective and strategic design can often mitigate the negative effects of extraneous CL. Beyond CL, many other factors affect the efficiency and capacity of working memory, specifically in the proposed central executive, including attention, fatigue, stress, anxiety, motivation, noise, ability, and age (Staal, 2004). These factors can explain why humans are often irrational or inconsistent in decision making.

Emotion & Working Memory Capacity. Emotion is directly tied to human performance. The effects of anxiety and motivation modify how humans respond to information in the world. Arousal theory, a dominant theory based on the work of Yerkes & Dodson (1908), assumes that arousal "represents the level of central nervous system activity… ranging from sleep to alertness," meaning it explains a human's energy level. The theory posits arousal "mobilizes and regulates the human stress response" (Staal, 2004, pg. 3). Because anxiety and motivation occur in the central executive part of Baddeley's model, the human stress response can either be aroused just enough so anxiety can serve as motivation to focus and accomplish a task leading to optimal performance, or too much arousal can degrade performance with an overwhelming amount of anxiety (Eysenck et al. 2007). When anxiety takes over and turns into worry, it imposes a greater load and there is less attention available for processing or room for storage. In this way, emotion can also limit the capacity of working memory. When anxiety serves as a motivating factor by increasing willingness, humans will experience peak performance levels, be able to make connections quicker, and learn new information easier resulting in the creation of smaller chunks to process and more room in working memory for other material. Anxiety also has the ability to overload the PL with inner verbal activity when humans contend with anxiety in their heads (Eysenck et al., 2007).

Trello Application. Trello is a digital organization tool that can be visualized as a corkboard where humans can track, organize, and manage endless information through familiar lists, cards, checklists, and calendars. With limited capacity in working memory, humans can only retain and process so much which is why to-do lists and big projects can be overwhelming. Trello allows humans to break down tasks into smaller, easier to process chunks by writing it down on a

card or breaking the project into a list with step-by-step tasks to ultimately keep important information top of mind **(Figure 1)**. These cards and lists can be associated with dates that can be viewed on a calendar **(Figure 2)**. By moving information from working memory to a card or list, humans are leveraging the VSS because they can "see" a logical process to work through.

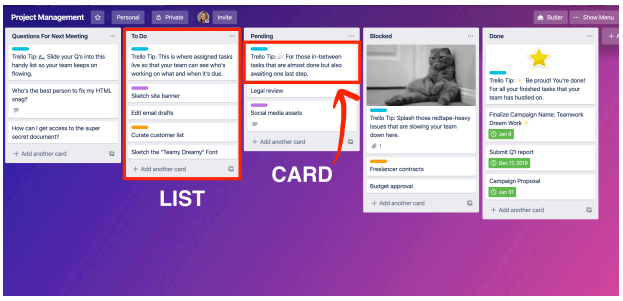

Figure 1: This figure displays Trello's ability to add cards associated with custom lists. Lists are used as headings to group cards, while cards hold tasks with information such as priority, due date, subtasks, etc.

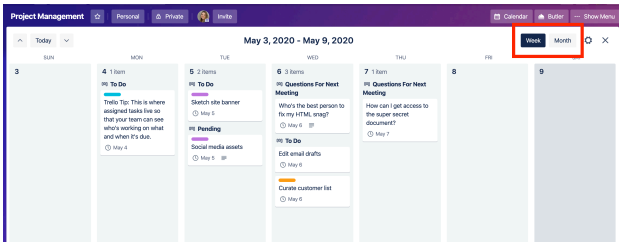

Figure 2: Trello can display cards, sorted by the list title, on a calendar in either a week or month view. This can make it easy for users to prioritize tasks and limit the load on working memory.

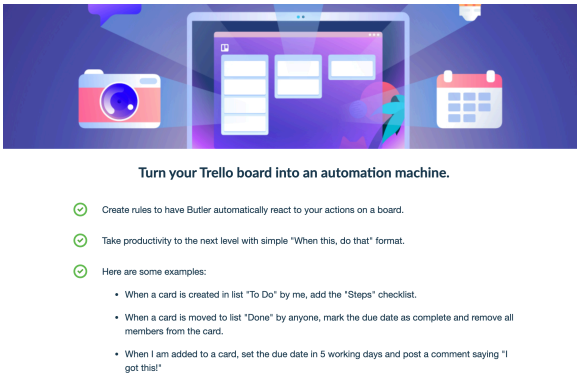

Figure 3: Trello's Butler can create custom helpful automation and templates for users to aid in efficiency and reduce cognitive load on working memory. Automation can remove burden from users by implementing processes so they don't have to worry about it.

Trello also has built-in automation through its "Butler" function. The Butler analyzes the users' usage and data and suggests helpful automation or templates that can be activated through the click of the button **(Figure 3)**. Powerful automation like this can reduce the load and burden imposed on the user when organizing their processes in Trello. With such a limited capacity in working memory, anxiety surrounding tasks users need to do for work or school can be overwhelming, but Trello helps by freeing up working memory. For example, a student could use automation to automatically sort their homework to prioritize upcoming deadlines, apply priority to projects associated with many tasks that would decrease the load on the central executive, and hide information that is not currently relevant so it does not distract and use working memory space.

Limited Duration and Highly Volatile

If not rehearsed, working memory has a limited duration of how much information can be remembered and committed to LTM (Kane & Engle, 2000). As a basic example, humans will easily forget a phone number if they do not rehearse it in their mind or utilize a measure such as writing it down. Brown (1958) and Peterson (1959) both studied this short duration and concluded that when humans cannot rehearse incoming information, recall of the information is often inaccurate, and it drops rapidly to near 0 after 15-25 seconds (Greene, 1996).

New information is constantly entering working memory and asking for attention since the world is full of distractions. Because of this, working memory is highly volatile. If the information in working memory is interrupted without rehearsal, it will not be retained (Peterson & Peterson, 1959). Humans can overcome some limitations using strategies such as rehearsing information covertly, creating relationships to form smaller chunks, putting the information into the world through writing or sketching, and relating to past information to draw from LTM (Cowan, 2010).

In the VSS, navigational information is also limited to about 15 seconds before being forgotten as Loftus et al. (1979) described, this explains why navigational directions are often so difficult to remember if a human is not familiar with the location. Similarly, in the PL, longer words and sentences are recalled less (Baddeley, 2003). A split-attention effect exists which explains how humans learn and retain information better when visual information, from the VSS, is accompanied by auditory verbal information, from the PL (Mayer & Moreno, 1998). The central executive is also vital because it aids in rejecting and inhibiting interference and maintaining the relevant active information (Kane & Engle, 2002, 2004). Many researchers theorize about whether decay over time or interference leads to forgetting information in the processing system. The case can be made on both sides and could be a combination of the two, working memory decay over time due to aging, ability, and distraction can lead to the interference of irrelevant information (Baddeley, 2002). It is critical to human processing performance to maintain the right information in working memory by not allowing interference to take control because "plans, goals, and tasks are more easily retrieved from long-term memory when no interference is present" (Coolidge & Wynn, 2005, pg. 8).

Emotion & Working Memory Volatility. Anxiety and motivation also have relevance when considering the high volatility and limited duration of working memory. The processing efficiency theory asserts "anxiety impairs processing efficiency more than it does performance effectiveness" (Eysenck et al., 2007). They explain the more recent attentional control theory updated the former theory by stating anxiety can reduce attentional control and impair the ability to use the "inhibition and shifting functions" (pg. 338). Inhibition is when humans, within the central executive, can "resist disruption or interference from task-irrelevant stimuli," and shifting is when humans "shift the allocation of attention to remain focused on task-relevant stimuli" (pg.

339). Therefore, humans can overcome working memory's limited duration and high volatility issues by leveraging emotion. They can resist interfering information by exercising anxiety to stay motivated and remain focused or shift their attention to information requiring high priority.

Trello Application. Trello leverages the abilities of working memory by understanding its limited duration and high volatility. Many humans will write down a to-do list when feeling overwhelmed with everything they need to manage, but few will understand how to best work through this list. For example, students tend to write projects down such as 'write the paper,' but they often fail to see the steps associated with that task. Experts may have an easier time with this, but novices will find value in Trello's ability to add checklists to cards associated with a task as well as set a notification so the card is rehearsed and not forgotten. In this way, students can use the limited duration of working memory to accomplish a very focused task such as "look up X researcher" **(Figure 4)**. Similarly, this function will decrease interference and help users remain focused and driven. When humans can check-off multiple to-dos, they will feel good about their productivity and the check-off will be motivating. Motivation is an inhibitor of distractions and is key to focus. What could have been an overwhelming project full of paralyzing anxiety can be easier to process thanks to Trello's abilities.

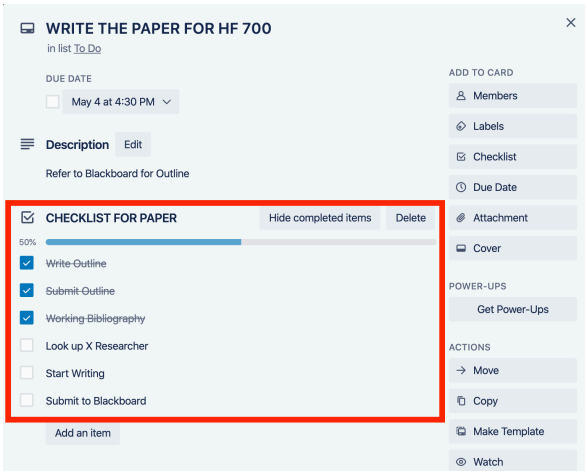

Figure 4: Trello cards can hold a wide variety of information that take to-do lists to the next level. Cards can be tasks that have checklists within them to further 'brain dump' what needs to be done and reduce the load on working memory. Cards give users the ability visualize and prioritize everything that needs to be done to

Conclusion

Working Memory is a limited capacity, limited duration, and highly volatile system which is influenced by human emotion and affects human cognitive processing. When designers consider ways to limit the potential load on a user's working memory by having a deep understanding of the user's abilities and preferences, their designs will be easier and more efficient to learn and use—Trello is a great example of this. Designers can augment working memory limitations by considering ways to automate processes, reduce cognitive load to avoid pushing users away, and remove the burden from falling on the user whenever possible.

References

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes.

Baddeley, A. D. (1992). Working memory. *Science, 255*(5044), 556-559.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, (11): 417-423.

Baddeley, A. D. (2002). Is working memory still working? *European psychologist, 7*(2), 85.

Baddeley, A. D. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839. doi:10.1038/nrn1201

Baddeley, A. D. (2010). Working memory. *Current biology, 20*(4), R136-R140. doi:10.1016/j.cub.2009.12.014

Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of learning and motivation* (Vol. 8, pp. 47-89). Academic press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In *Models of working memory: Mechanisms of active maintenance and executive control*. (pp. 28-61). New York, NY, US: Cambridge University Press.

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, *10*(1), 12-21.

Coolidge, F. L., & Wynn, T. (2005). Working memory, its executive functions, and the emergence of modern thinking. *Cambridge archaeological journal, 15*(1), 5-26.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and brain sciences*, *24*(1), 87-114.

Cowan, N. (2010). The Magical Mystery Four. *Current Directions in Psychological Science, 19*(1), 51-57. doi:10.1177/0963721409359277

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and Performance: The Processing Efficiency Theory. *Cognition and Emotion, 6*(6), 409-434. doi:10.1080/02699939208409696

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion, 7*(2), 336.

Goldman-Rakic, P. (1992). Working Memory and the Mind. *Scientific American, 267*(3), 110-117. Retrieved May 1, 2020, from www.jstor.org/stable/24939217

Greene, R. L. (1996). The influence of experimental design: The example of the brown-peterson paradigm. *Canadian Journal of Experimental Psychology/Revue Canadienne De Psychologie Expérimentale, 50*(2), 240-242. doi:http://dx.doi.org.ezp.bentley.edu/10.1037/1196-1961.50.2.240

Haberlandt, K. (1997). *Cognitive psychology*. Allyn & Bacon.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 336.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic bulletin & review, 9*(4), 637-671. doi:10.3758/bf03196323

Kane, M. J., & Engle, R. W. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of learning and motivation*, *44*, 145-200.

Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. In: Elsevier.

Loftus, G. R., Dark, V. J., & Williams, D. (1979). Short-term memory factors in ground controller/pilot communication. *Human Factors*, *21*(2), 169-181.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of educational psychology*, *90*(2), 312.

McLeod, S. A. (2012). *Working memory*. Simply Psychology. https://www.simplypsychology.org/working%20memory.html

McLeod, S. A. (2013, August 05). *Stages of memory - encoding storage and retrieval*. Simply Psychology. https://www.simplypsychology.org/memory.html

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). Plans and the structure of behavior.

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control*. Cambridge University Press.

Morey, C. C., & Cowan, N. (2005). When do visual and verbal memories conflict? The importance of working-memory load and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(4), 703.

O'Reilly, R. C., Braver, T. S., & Hall, B. (1997). A Biologically-Based Computational Model of Working Memory.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63-71.

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of experimental psychology, 58*(3), 193.

Staal, M. A. (2004). Stress, cognition, and human performance: A literature review and conceptual framework.

Sternberg, R. J. (1999). *Cognitive psychology (2nd ed.)*. Fort Worth, TX: Harcourt Brace College Publishers.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. *The Cambridge handbook of multimedia learning, 3*(2), 19-30.