The Impact of Memory Load and Emotion on Human Performance

April 2021 · 12 min read

Tara Sethi

Introduction

Memory, a critical cognitive process, allows humans to retrieve, store, and encoded information in the brain (Howell, 2020). This information often consists of previously learned facts and experiences (Memory, 2016). Despite some debate, notable research has uncovered three different forms of memory: sensory, long-term, and working memory (Cowan, 2008). Each of these memory forms plays an important role in human performance and the perception of products. Working memory, in particular, is crucial in guiding human decision making and behavior. However, several characteristics of working memory limit human performance—such as being limited capacity, time-constrained, and highly volatile (Eriksson et al., 2015; Baddeley & Hitch, 1974; Blasiman & Was, 2018).

The following paper will consider how, despite memory limitations, product designers can assist human decision making and behavior through performance support. First, we will consider the interplay among different memory systems and discuss various memory processes. Then, these processes will be examined in the context of memory load and emotion. Finally, the relationship between memory systems and product performance will be demonstrated through a review of an official government website: the New Hampshire Vaccine and Immunization Network Interface.

Types of Memory

Upon encountering an interface, sensory memory allows humans to hold sensory information for around half a second to three seconds (Hall & Stewart, 2010). In this automatic system, free of cognitive control, each sensory channel has storage that works to prolong stimulus representation (Lumen Learning, 2021). These channels help to transfer sensory information to working memory—where humans briefly store limited amounts of new information (Eriksson et al., 2015). Working memory, a system guided by attention, works to code information phonetically, semantically, and visually (Vallar & Baddeley, 1984; Demb et al., 1995; Harrison et al., 2009). The duration in which working memory can hold information decays as the volume of information increases due to working memory's limited capacity (Cowan, 2001). Regardless, working memory supports metacognitive and cognitive processes such as decision making,

error monitoring, and reading comprehension. Working memory also allows humans to store new information in long-term memory—which has the potential to store information for an infinite amount of time and has an unlimited capacity (Eriksson et al., 2015). To access long-term memory, humans use cognitive frameworks like schemas to link to existing knowledge and reactivate information (Piaget, 1964). Here, humans either activate the appropriate framework or create new ones (Piaget, 1964). Ericsson and Kintsch (1995) refer to the skilled retrieval of stored memory during task performance as long-term working memory.

The Role of Working Memory

In the modal model, Atkinson and Shiffrin (1968) proposed that of a large amount of sensory information humans collect from the environment, most of it is forgotten. However, the authors suggested some of this sensory information enters a working memory, where “it receives selected inputs from the sensory register and also from long-term store” (Atkinson and Shiffrin, 1968). Atkinson and Shiffrin stressed humans have a separate short-term store with limited capacity that assists in several cognitive activities (Baddeley et al., 2019). Later on, Baddeley and Hitch advanced the field of working memory as they conducted further research (Adams et al., 2018).

Baddeley and Hitch

Building upon the modal model, Baddeley and Hitch proposed working memory could be divided into specialized stores. The authors suggested working memory has three subsystems that help humans to store and code information: phonological store and loop, visuospatial sketch pad, and the central executive (Baddeley and Hitch, 1974). The phonological loop supports the temporary store of auditory memory, such as words and sounds, via the phonological store and a rehearsal system. Meanwhile, the visuospatial sketch pad uses visual images to represent information. The central executive, which controls attention, is responsible for rehearsal routines and retrieving information (Baddeley and Hitch, 1974). Later, Baddeley (2000) altered the existing framework to include a fourth component: the episodic buffer. The episodic buffer works to integrate information from different sources and helps to explain “cross-domain associations in working memory, such as the retention of links between names and faces” (Adams et al., 2018). This buffer also accommodates the potential for long-term memory to influence working memory (Baddeley, 2000).

Cowan and Barrouillet

Unlike the Baddeley model, Cowan (1988) proposed a more general framework for working memory and information processing. Instead of emphasizing separate stores of working memory, Cowan proposed that “new input overwrites or interferes with previous activated information with similar features” (Adams et al., 2018). Meaning, as humans shift their attention,

information refreshes rapidly. Cowan's model of attention-based, capacity-limited decay counters Baddeley's model of time-based decay (Cowan, 2016). Cowan also avoids separating phonological and visuospatial stores, believing these processes are too complex and may overlap. Like Cowan, Barrouillet and Camos's (2012) model of working memory focuses on attention rather than rehearsal. The authors propose that humans can refresh decaying memory sources through attentional focusing (Barrouillet and Camos, 2012). This concept is based upon the time-based resource-sharing (TBRS) model (Barrouillet and Camos, 2012).

Characteristics of Working Memory

Limited Capacity

Whether a result of attention or time, researchers agree working memory has a limited capacity that constrains the amount of information humans can store while completing cognitive tasks. Studies have shown humans can hold about three to five items of information in working memory at a time (Cowan, 2001). However, there are several factors that can diminish or extend capacity depending on the situation. For example, working memory capacity can be elongated through the process of chunking—where items are grouped into a single cognitive unit (Thalmann et al., 2019). Furthermore, the dual coding theory suggests that if information is offered to humans in different ways (e.g., words and images), humans can access more working memory capacity (Clark & Paivio, 1991). Despite these methods to increase working memory capacity, several factors can lead to decay. For instance, Mattay et al. (2006) found that age-related changes in the brain can lead to reduced activity in prefrontal regions of the cortex, causing older adults to lose working memory capacity.

Time Constrained

In addition to having limited capacity, researchers have found information in working memory can only be stored for 15 to 30 seconds (Prisko, 1963). This duration can become even shorter when rehearsing of information is interrupted by distractions in the environment, causing attention to shift towards new information (Cowan, 2001; Barrouillet & Camos, 2012). Moreover, researchers have also found that the more information humans must store in working memory, the faster decay will be (Barrouillet et al., 2004). Rehearsal strategies, such as repeating information internally or saying information aloud, can prolong the storage of information (Comblain, 1994). Although, in most cases, more rapid decay will occur.

Highly Volatile

The performance of working memory can fluctuate significantly depending on individual circumstances and the presentation of information. Blasiman and Was (2018) suggest factors such as age, intelligence, gender, personality, mental and medical conditions, stress, anxiety,

and fatigue can all impact working memory performance (Blasiman & Was, 2018). Prominent research proposes that humans, when focused on specific information instead of their general surroundings, can suffer from inattentional blindness—which occurs when humans fail to see highly salient objects as a result of a lack of attention (Mack & Rock, 1998). In terms of interface design, the split-attention effect suggests that performance declines when humans take in information from spatially separated sources, even if those sources refer to the same concept (Chandler & Sweller, 1992). However, more recent research suggests that the distance between spatially separated information must be quite large for this effect to occur (Pouw et al., 2019).

Impacts of Memory Load and Emotion

Cognitive Load

Barrouillet et al. (2007) describe cognitive load as “a function of the time during which [an] activity occupies the central executive by involving executive functions.” Sweller (2005) identifies three sources of cognitive load—intrinsic, germane, and extraneous. Intrinsic load relates to the minimum load based on the complexity of the material to be learned, while a germane load is associated with the construction and commitment of schemas to long-term memory. Extraneous load occurs when instructional technique or information does not aid in schema construction in long-term memory. Researchers have found that cognitive load can have a detrimental effect on learning and task performance (Sweller, 1988; Chen & Chang, 2009). Due to working memory’s limited capacity, a high cognitive load increases the chance information will not enter long-term memory.

Emotion

Unrelated to the product components, several emotional aspects impact the degree of load humans experience. Both anxiety and motivation contribute to human arousal and can significantly impact working memory performance. Eysenck and Calvo (1992), examining the anxiety-performance relationship, determined that anxiety can significantly impair processing efficiency, having an adverse effect on performance (Esyenck & Calvo, 1992). However, the authors note the effects of anxiety on performance effectiveness also depend on the use of additional resources and the level of task demand on working memory (Esyenck & Calvo, 1992). Furthermore, Esyenck and Calvo (1992) claim that anxiety can have some positive effect as “worry can also lead to increased motivation to improve performance.”

Motivation, a key process that guides human behavior, has the potential to extend humans’ biological and cognitive capabilities, as well as help humans overcome limitations that would overwise adversely affect performance (Szatkowska et al., 2008; Hoffman & Schraw, 2009). In a study evaluating mind wandering and reading comprehension, Unsworth and McMillan (2013) found that wandering while reading was influenced not only by working memory capacity, but

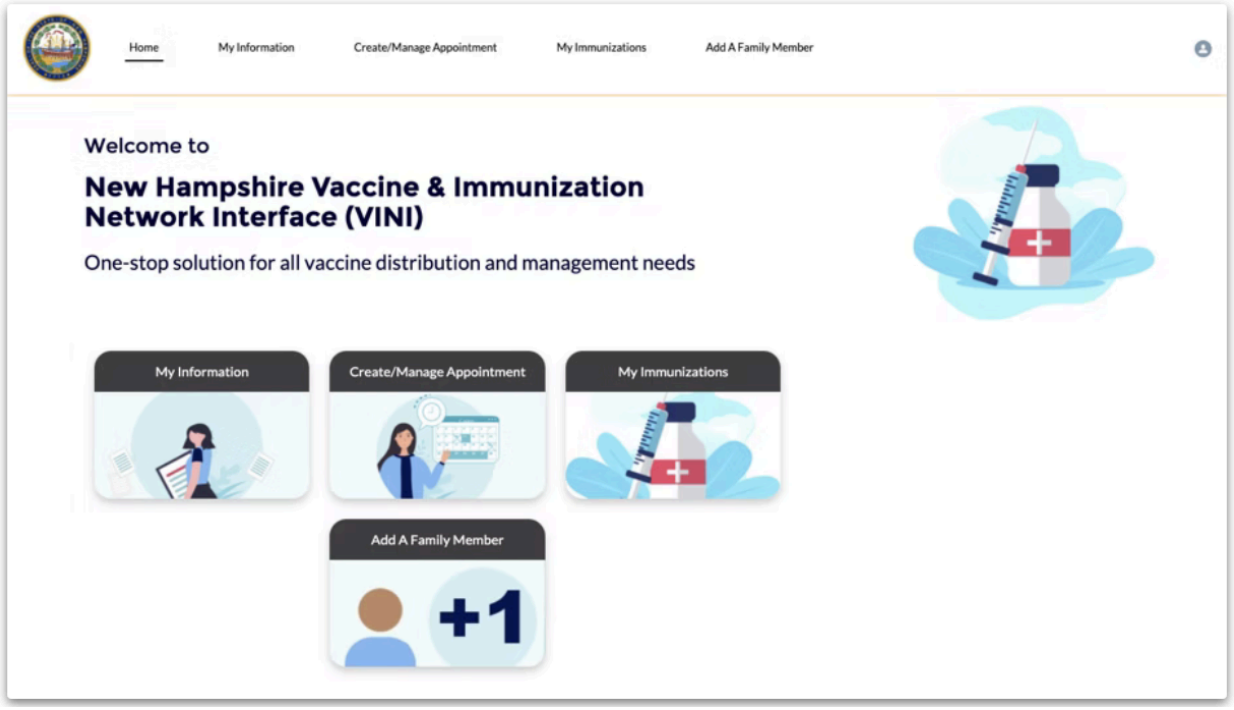
also topic interest and motivation. The authors determined that “low levels of interest led to low levels of motivation, which, in turn, led to higher rates of mind wandering” and lower reading comprehension (Unsworth & McMillian, 2013). Beyond motivation and anxiety, designers should consider other stressors, such as fatigue, frustration, and anger, that can increase cognitive load and decrease working memory performance.

Product Review

To reduce cognitive load and anxiety for users, designers must be wary of using interface components that place a high demand on working memory. These considerations become even more crucial when designing for processes that have several steps and a high information load. Demonstrating this case, we will review the New Hampshire COVID-19 Vaccine registration website (vaccines.nh.gov). As a public website, this design must support a wide range of users who vary in age, computer literacy, and cognitive and physical ability.

Once registered for the vaccine, users receive an email prompting them to activate their account and log in to the New Hampshire Vaccine and Immunization Network Interface (VINI). The VINI home page allows users to review personal information, create and manage appointments, review immunizations, and add family members to make scheduling more convenient (see Figure 1). At first glance, low information density and a high degree of white space help to reduce visual noise. The use of familiar images and terminology on the four cards help to match users’ existing schemas. These elements help to reduce the load for users who may already be anxious about securing a vaccination appointment promptly.

Figure 1
VINI Home Page

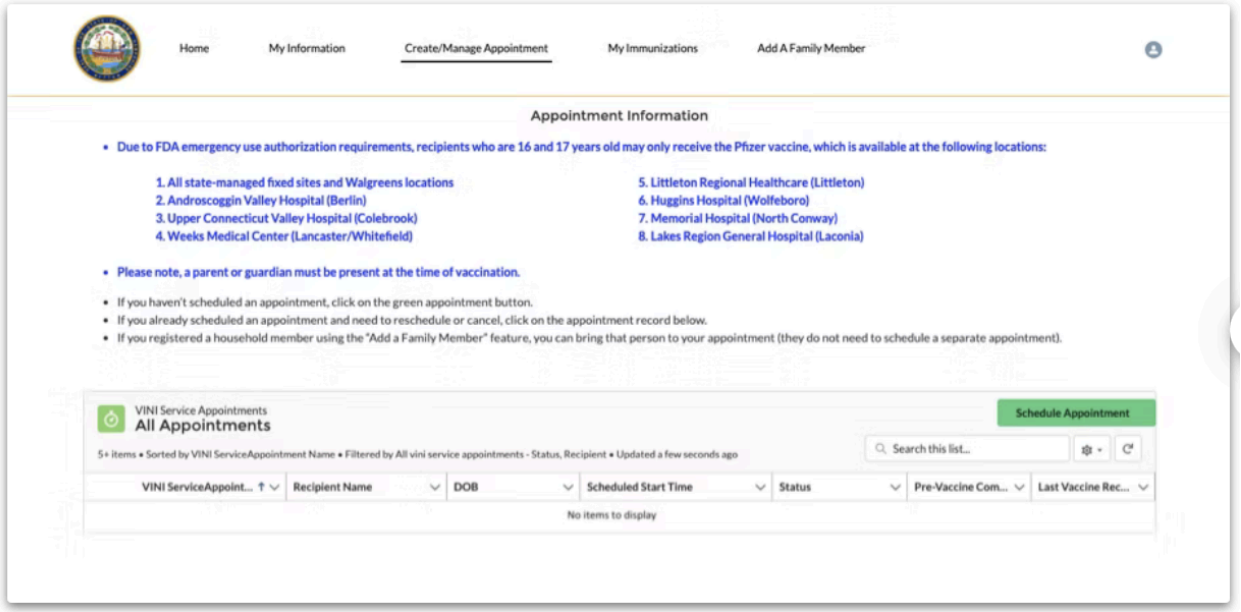


Note. From the State of New Hampshire [Photograph], by the State of New Hampshire 2021.

However, the header could benefit from using more basic terminology. For example, “network interface” could be replaced with more common language such as “portal”. Doing so would also eliminate the need for the “VINI” acronym used across the site. In terms of redundancy, the top-level navigation and the cards shown in the middle of the page perform the same action. This duplication of information may cause extraneous load, which can reduce accessibility for blind users (Giraud et al., 2018).

Clicking the Create/Manage Appointment card or navigation tab, users land on the Create/Manage Appointment page where they can schedule a vaccine appointment (see Figure 2). Unfortunately, many page elements distract from this crucial functionality. For one, the appointment information in blue text calls out details that do not apply to all users (see Figure 2). Besides, due to limited working memory capacity, users who do need this information are unlikely to remember the information completely once they progress to the following scheduling steps. Thus, information should be limited to the defined task. Users who have not scheduled an appointment before do not need to be shown the VINI Service Appointments table. In addition, the information shown in the blue text should be presented in context (such as when users are asked to select the appointment location).

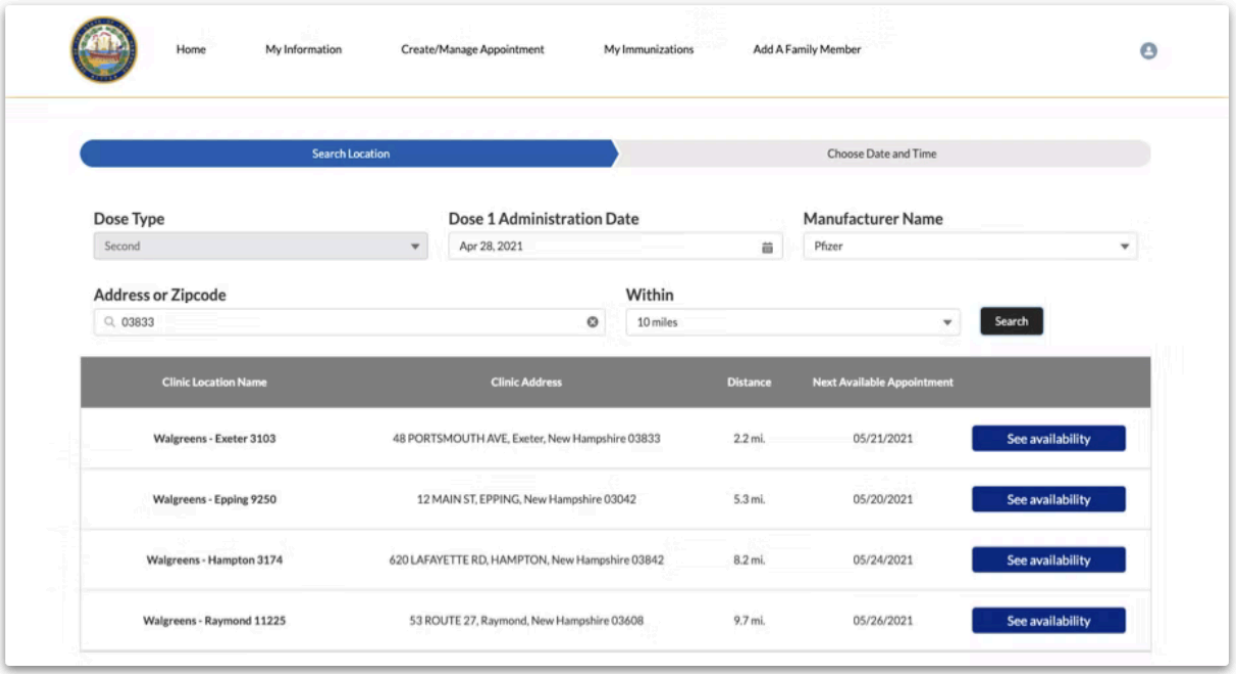
Figure 2
VINI Create/Manage Appointment Page



Note. From the State of New Hampshire [Photograph], by the State of New Hampshire, 2021.

After clicking on the Schedule Appointment button on the Create/Manage Appointments page, users progress to the next page, where they can search for appointment locations (see Figure 3). The progress bar at the top of the page helps to remind users where they are in the scheduling process. Leveraging progressive disclosure, clinic locations do not appear until users enter the dose type, manufacture name, address or zip code, and distance. Once selected, results are shown in order of proximity, listed in the center table (see Figure 3). The current system does not give users the flexibility to filter results by different criterium or “decision weights” (Kahneman, 1979). For example, some users may be more interested in viewing locations in order of the next available appointment while others may prefer to visit a state-run vaccination site versus a private clinic. The addition of filters would allow the system to respond to individuals’ preferences—helping to support the decision-making process by optimizing choice.

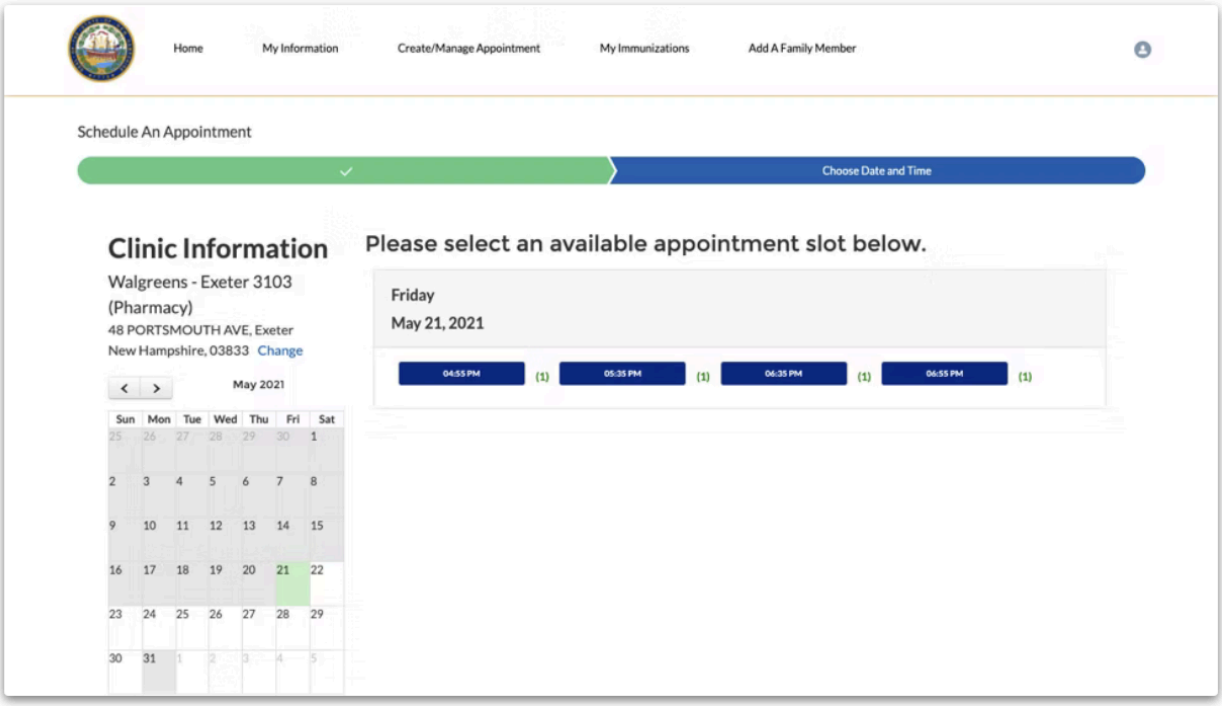
Figure 3
VINI Search Location Page



Note. From the State of New Hampshire [Photograph], by the State of New Hampshire, 2021.

Next, users select an appointment location by clicking on the See availability button (see Figure 3). This button brings users to the Schedule An Appointment page where available appointment time slots are shown by day (see Figure 4). The lack of escape hatches on this page are likely to cause frustration for users as the only way users can exit the Schedule An Appointment page is by clicking on the blue link labeled change, located by the clinic address (see Figure 4). After clicking change, users are brought back to the Search Location page. However, the system does not remember information that was previously selected. Instead, users must complete the search progress from the beginning. Likewise, using the browser back button from the Schedule An Appointment page brings users back to the Create/Manage Appointments page. For users trying to compare appointment options quickly, the inability to seamlessly browse availability is likely to cause increased anxiousness and cause unnecessary frustration.

Figure 4
VINI Choose Date and Time



Note. From the State of New Hampshire [Photograph], by the State of New Hampshire, 2021.

Once users have selected an appointment, a confirmation page and corresponding email provide feedback. Despite some significant areas for improvement, the consistent color scheme and page layout of the VINI website help to reduce anxiety by maintaining predictability.

Conclusion

In government websites, which have a responsibility to support all users, designers must pay careful attention to the load imposed by the system. These considerations are even more crucial in situations, such as scheduling the COVID-19 vaccine, where users are under time pressure and may already feel anxious due to environmental stressors. Furthermore, public websites must assist aging populations and those with cognitive disabilities who have decreased working memory capacity and potentially less experience using computers. The design should support learning by helping users call upon appropriate mental models or develop new schemas. In doing so, designers can help reduce the risk of causing negative emotions and fatigue throughout the user experience.

References

Adams, E. J., Nguyen, A. T., & Cowan, N. (2018). Theories of Working Memory: Differences in Definition, Degree of Modularity, Role of Attention, and Purpose. Language, speech, and hearing services in schools, 49(3), 340–355. https://doi.org/10.1044/2018_LSHSS-17-0114

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), The psychology of learning and motivation: Advances in research and theory. (Vol. 2, pp. 89-195). New York: Academic Press.Return to ref 1968 in article

Baddeley, A. D., Hitch, G. J., & Allen, R. J. (2019). From short-term store to multicomponent working memory: The role of the modal model. Memory & cognition, 47(4), 575-588.

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

Baddeley, A. (2000). The episodic buffer: a new component of working memory?. Trends in cognitive sciences, 4(11), 417-423.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. Journal of Experimental Psychology: General, 133(1), 83.

Barrouillet, P., Bernardin, S., Portrat, S., Vergauwe, E., & Camos, V. (2007). Time and cognitive load in working memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(3), 570.

Barrouillet, P., & Camos, V. (2012). As time goes by: Temporal constraints in working memory. Current Directions in Psychological Science, 21(6), 413-419.

Blasiman, R. N., & Was, C. A. (2018). Why Is Working Memory Performance Unstable? A Review of 21 Factors. Europe's journal of psychology, 14(1), 188–231. https://doi.org/10.5964/ejop.v14i1.1472

Chandler, P., & Sweller, J. (1992). The split‐attention effect as a factor in the design of instruction. British Journal of Educational Psychology, 62(2), 233-246.

Chen, I., & Chang, C. C. (2009). Cognitive load theory: An empirical study of anxiety and task performance in language learning.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. Educational psychology review, 3(3), 149-210.

Comblain, A. (1994). Working memory in Down's syndrome: Training the rehearsal strategy. Down's Syndrome, Research and Practice, 2(3), 123-126.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information-processing system. Psychological bulletin, 104(2), 163.

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. (2008). What are the differences between long-term, short-term, and working memory?. Progress in brain research, 169, 323–338. https://doi.org/10.1016/S0079-6123(07)00020-9

Cowan, N. (2016). Working memory capacity: Classic edition. Psychology press.

Demb, J. B., Desmond, J. E., Wagner, A. D., Vaidya, C. J., Glover, G. H., & Gabrieli, J. D. (1995). Semantic encoding and retrieval in the left inferior prefrontal cortex: a functional MRI study of task difficulty and process specificity. Journal of Neuroscience, 15(9), 5870-5878.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. Psychological review, 102(2), 211.

Eriksson, J., Vogel, E. K., Lansner, A., Bergström, F., & Nyberg, L. (2015). Neurocognitive architecture of working memory. Neuron, 88(1), 33-46.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. Cognition & emotion, 6(6), 409-434.

Giraud, S., Thérouanne, P., & Steiner, D. D. (2018). Web accessibility: Filtering redundant and irrelevant information improves website usability for blind users. International Journal of Human-Computer Studies, 111, 23-35.

Hall, J., Stewart, M. E. (2010). 5 - Basic psychology. Companion to Psychiatric Studies (Eighth Edition), Churchill Livingstone, 95-108, https://doi.org/10.1016/B978-0-7020-3137-3.00005-X.

Harrison, S. A., & Tong, F. (2009). Decoding reveals the contents of visual working memory in early visual areas. Nature, 458(7238), 632–635. https://doi.org/10.1038/nature07832

Hoffman, B., & Schraw, G. (2009). The influence of self-efficacy and working memory capacity on problem-solving efficiency. Learning and Individual Differences, 19(1), 91-100.

Howell, C. R. (2020). Types of memory. In Gale Science Online Collection. Gale. https://link.gale.com/apps/doc/BBRSUN848077296/SCIC?u=mlin_m_bent&sid=SCIC&xid=60a88167

Kahneman, D. (1979). Prospect theory: An analysis of decisions under risk. Econometrica, 47, 278.

Lumen Learning (2021). Boundless Psychology. Memory: Storage. Retrieved from https://courses.lumenlearning.com/boundless-psychology/chapter/types-of-memory

Mack, A., & Rock, I. (1998). Inattentional blindness. MIT press.

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Berman, K. F., Das, S., ... & Weinberger, D. R. (2006). Neurophysiological correlates of age-related changes in working memory capacity. Neuroscience letters, 392(1-2), 32-37.

Memory. (2016). In J. L. Longe (Ed.), The Gale Encyclopedia of Psychology (3rd ed., Vol. 2, pp. 729-733). Gale. https://link.gale.com/apps/doc/CX3631000491/SCIC?u=mlin_m_bent&sid=SCIC&xid=e523a131

Piaget, J. (1964). Cognitive development in children: Piaget. Journal of research in science teaching, 2(3), 176-186.

Pouw, W., Rop, G., De Koning, B., & Paas, F. (2019). The cognitive basis for the split-attention effect. Journal of Experimental Psychology: General, 148(11), 2058.

Prisko, L. H. (1963). Short-term Memory in Focal Cerebral Damage. McGill University. Retrieved from http://digitool.library.mcgill.ca/webclient/DeliveryManager?pid=115219&custom_att_2=direct

State of New Hampshire. COVID-19 Vaccine for NH Residents. NH Vaccine Strategy. (2021). https://www.vaccines.nh.gov/.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. Cognitive science, 12(2), 257-285.

Sweller, J. (2005). Implications of Cognitive Load Theory for Multimedia Learning.

Szatkowska, I., Bogorodzki, P., Wolak, T., Marchewka, A., & Szeszkowski, W. (2008). The effect of motivation on working memory: An fMRI and SEM study. Neurobiology of learning and memory, 90(2), 475-478.

Thalmann, M., Souza, A. S., & Oberauer, K. (2019). How does chunking help working memory?. Journal of experimental psychology. Learning, memory, and cognition, 45(1), 37–55. https://doi.org/10.1037/xlm0000578

Unsworth, N., & McMillan, B. D. (2013). Mind wandering and reading comprehension: Examining the roles of working memory capacity, interest, motivation, and topic experience. Journal of Experimental Psychology: Learning, Memory, and

Cognition, 39(3), 832.

Vallar, G., & Baddeley, A. D. (1984). Fractionation of working memory: Neuropsychological evidence for a phonological short-term store. Journal of Verbal Learning and Verbal Behavior, 23(2), 151-161.