

Memory, Load and Emotional Subsystems

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Introduction

Working memory plays a critical role in human cognition, serving as the evolutionary framework within which individuals temporarily store and manipulate information necessary for task execution (Baddeley, 2010). This cognitive system evolved as a crucial adaptation enabling humans to maintain goal-directed behavior, solve complex problems, and navigate social interactions—all providing significant evolutionary advantages in human development. Working memory inherently operates under several fundamental limitations as revealed by cognitive research: it can hold only a small number of elements (approximately 3-5 items according to Cowan's revised estimates), information rapidly decays within 15-30 seconds unless actively maintained through rehearsal, and its contents are highly susceptible to disruption when attention is diverted (Miller, 1956; Cowan, 2001).

This paper delves into these challenges, underscoring the importance of understanding working memory's boundaries to design effective interfaces, systems, and environments that enhance human performance. Key sub-elements of working memory include the phonological loop (verbal information processing), visuospatial sketchpad (visual and spatial information), episodic buffer (integrating information), and central executive (attentional control) (Baddeley & Hitch, 1974). Additionally, this analysis extends to how the emotional state of users profoundly impacts their cognitive load and overall experience, emphasizing the necessity of considering emotional influences when assessing working memory function.

For the case study aspect of this paper, I will be evaluating the Overseas Citizenship of India (OCI) Service's new user experience—a complex governmental digital interface that requires users to navigate multiple steps while maintaining various pieces of information in working memory. This evaluation will apply evidence from the literature review with a specific focus on how the interface design either supports or taxes working memory, affecting usability, user experience, and human performance.

Working Memory Models

First, I will discuss the framework for understanding human memory. It sets a foundational understanding, clarifies core concepts, and enhances ease of comprehension, enabling learners to better grasp the significance and functionality of working memory. Such an approach also facilitates comparative analysis between different models, boosts motivation by highlighting the relevance of working memory in daily activities, and prepares learners for more complex topics. Alan Baddeley and Graham Hitch proposed the Multicomponent Memory Model in 1974 which presents a comprehensive framework for understanding the structure and function of human memory. The Multicomponent Model of Working Memory has wide-reaching implications across various domains, enhancing our understanding of cognitive architecture and providing a basis for practical applications in education, clinical settings, interface design, and beyond. The model consists of three main components and a fourth added later. The components are listed as such:

1. **Central Executive:** The central executive is the control center of the memory system, responsible for coordinating cognitive processes and allocating attentional resources. It oversees and directs attention to specific tasks, regulates cognitive activities, and integrates information from the other two components. The central executive is flexible and adaptable, enabling individuals to switch between different tasks, maintain goals, and solve problems. The central executive is the most important, complex, but least understood component of WM. “Individuals differ in the capacity of their various working memory subsystems in ways that influence scholastic achievement” (Baddeley, 2006).
2. **Phonological Loop:** The phonological loop is responsible for the temporary storage and rehearsal of verbal and auditory information. It consists of two subcomponents: the phonological store,

which holds speech-based information for a brief duration, and the articulatory control process, which allows for the rehearsal and maintenance of information through subvocal articulation. This component is particularly susceptible to interruptions, as its contents rapidly decay and exhibit significant volatility when attentional resources are diverted, explaining why verbal information becomes fragmented or lost during multitasking (Baddeley & Hitch, 1974). The phonological loop plays a crucial role in tasks involving language comprehension, verbal learning, and serial recall. While Baddeley's model has been foundational, alternative theoretical perspectives from researchers like Cowan (2001) and Oberauer (2002) have emphasized the role of attentional focus and activated long-term memory representations rather than specialized storage buffers. "We began with a simple model that distinguished between a temporary store and a rehearsal process based on vocalization, which could be either overt or covert" (Baddeley & Hitch, 2019).

3. **Visuospatial Sketchpad:** The visuospatial sketchpad is responsible for the temporary storage and manipulation of visual and spatial information. It allows individuals to mentally represent and manipulate visual images, spatial relationships, and spatial configurations. The visuospatial sketchpad enables tasks such as mental rotation, navigation, and visualization, and it works in conjunction with the central executive to support visuospatial processing and problem-solving. This component has significant implications for cognitive load distribution, as visual and spatial information can be processed simultaneously with verbal information, allowing for more efficient distribution of attentional resources across multiple tasks (Logie, 2011). However, when visual and spatial tasks compete for the same resources, performance deteriorates substantially (Klauer & Zhao, 2004). "The visuospatial sketchpad is a system that parallels the phonological loop but has proved less easy to study" (Baddeley, 2006).
4. **Episodic Buffer:** In addition to these three components, Baddeley later proposed the episodic buffer as a fourth component of the model. The episodic buffer serves as a temporary storage system that integrates information from the phonological loop, visuospatial sketchpad, and long-term memory into a cohesive multimodal representation of experience and events. It provides a link between working memory and long-term memory, facilitating the encoding and retrieval of episodic memories. "The episodic buffer is assumed to be a limited-capacity temporary storage system that is capable of integrating information from a variety of sources" (Baddeley, 2000). Despite the versatility of these components, working memory still exhibits limitations, including restricted capacity and susceptibility to interference (Oberauer et al., 2016).

The introduction of the episodic buffer marked a significant update, enhancing the model's ability to integrate multimodal information with long-term memory. Later elaborations and recent updates focus on deepening the understanding of existing components, especially the complexity of the central executive, and aligning the model with neurological findings. When compared with other dominant models—such as Cowan's embedded-processes model emphasizing attentional focus, Oberauer's concentric model with its activated long-term memory layer, and Engle's executive attention framework focusing on inhibitory control—Baddeley's model stands out for its detailed component structure while sharing the fundamental recognition of capacity limitations and attentional control mechanisms (D'Esposito & Postle, 2015; Miyake & Shah, 1999). These various theoretical approaches reflect an evolution from a simpler modular view to a more integrated and biologically informed understanding.

Limitations of Working Memory

The limitations of working memory include its restricted capacity, short duration of retention, vulnerability to interference, finite processing speed, individual differences in capacity, susceptibility to cognitive load, and influence of emotional state (Baddeley, 2003; Conway et al., 2005). These constraints affect the ability to hold and manipulate information, requiring strategies to optimize cognitive performance

and task design. There are three types of cognitive loads or three ways our mind processes information. First is intrinsic load, which refers to the inherent complexity of a task or information, representing the cognitive resources required to process and understand the task itself. "Intrinsic cognitive load refers to the complexity of the knowledge that is being acquired without reference to how that knowledge is acquired" (Sweller, 2011). Second is germane load, or GCL, which refers to the cognitive effort invested in learning and understanding new information or concepts, contributing to the development of long-term memory and expertise in a particular domain. These cognitive load factors are significantly impacted by aging processes, fatigue states, and varying disabilities, with research showing particular vulnerability of working memory to these conditions (Salthouse, 2010; Lorist & Tops, 2003). GCL is the load imposed on working memory that can have a positive impact on learning. Therefore, unlike the other two loads, GCL is a productive load that helps with schema acquisition and automation" (Klepsch & Seufert, 2020). Importantly, cognitive load theory extends beyond learning contexts to all cognitive processing, affecting workplace performance, decision-making, problem-solving, and daily functioning (Paas et al., 2003; Kirschner et al., 2018). Lastly, extraneous load, or ECL, is the cognitive burden imposed by irrelevant or unnecessary elements in a learning task or environment, which may hinder the efficient processing and comprehension of relevant information. Another limitation is the high volatility of working memory (Oberauer & Kliegl, 2006; Kane et al., 2007). Human working memory is highly volatile, meaning it can fluctuate rapidly due to various factors such as attentional demands, emotional state, fatigue, environmental conditions, health status, task complexity, and individual differences. ECL results from the design of learning material. Therefore, to minimize ECL, anything that distracts the learner and hampers the learning process should be avoided in the design of learning material" (Klepsch & Seufert, 2020). The application of cognitive load principles extends to numerous domains beyond education, including interface design, organizational systems, and healthcare communication (Sweller et al., 2019).

These compounding factors intersect to influence the stability and functionality of working memory, impacting cognitive performance and attentional focus. Different types of interference (retroactive, proactive, and concurrent) directly impact Baddeley's working memory components, with phonological interference disrupting the phonological loop, visual interference affecting the visuospatial sketchpad, and attentional interruptions overloading the central executive (Lewandowsky et al., 2010; Oberauer et al., 2012). Understanding and managing these factors is crucial for optimizing working memory performance in different situations (Engle, 2002; Logie et al., 2021). Motivation, a key emotional factor, plays a crucial role in optimizing working memory by enhancing attention, cognitive control, and emotional regulation.

Emotional sub-systems

Emotions are closely intertwined in shaping user experience, impacting attention, memory, decision-making, and satisfaction. Positive emotions can enhance engagement and satisfaction, while negative emotions may impair cognitive processes (Tyng et al., 2017; Pekrun et al., 2011). Research demonstrates that positive affect broadens attentional scope and facilitates cognitive flexibility, while negative affect narrows attentional focus and reduces working memory capacity (Fredrickson & Branigan, 2005; Isen, 2008). Designing interfaces that leverage emotional engagement and support working memory may enhance usability and user satisfaction.

One factor that optimizes working memory and signals positive emotions is motivation. Motivation significantly influences working memory by enhancing attentional focus, cognitive control, persistence, effort, and emotional regulation. Motivated individuals allocate attention efficiently, exert greater cognitive control, invest more effort, and regulate emotions effectively, leading to improved working memory performance and task outcomes (Pessoa, 2009; Mather & Sutherland, 2011). This volatility contributes to common errors such as intrusion and transposition errors, highlighting the challenges of managing information within the limited capacity of working memory. Conversely, anxiety mainly impacts the emotional subsystems related to working memory by taxing the central executive, particularly through the mechanism of physiological arousal which plays a significant role in cognitive performance (Yerkes & Dodson, 1908; Eysenck et al., 2007). The inverted U-shaped relationship between arousal and performance explains why moderate levels of arousal can enhance working memory function,

while excessive arousal from anxiety depletes attentional resources and impairs cognitive processing (Diamond et al., 2007; Arnsten, 2009). This influence can lead to diminished cognitive flexibility, decreased working memory capacity, and an overall increased cognitive load, which collectively undermine cognitive performance.

Highly Volatile

Though previously discussed broadly, the specific manifestations of working memory volatility warrant deeper examination. In the context of the highly volatile nature of working memory, two common types of errors occur: intrusion errors and transposition errors. Intrusion errors involve irrelevant information intruding into working memory, particularly during time-constrained tasks, interruptions of ongoing cognitive processes, and interference from competing stimuli (Oberauer & Lewandowsky, 2014; Bancroft et al., 2013). For example, when a phone notification interrupts form completion, previously entered information may be displaced by the notification content. Conversely, transposition errors entail the rearrangement or swapping of items within working memory, such as reversing digits in a phone number (Henson, 1998; Hurlstone et al., 2014).

These errors highlight the challenges of managing information within the limited capacity of working memory and underscore the importance of effective encoding strategies and attentional control to optimize cognitive performance. Understanding these errors can inform interventions aimed at enhancing working memory functioning and reducing cognitive errors in various contexts (Logie et al., 2015; Morrison & Chein, 2011). Simplifying tasks to manage cognitive load, creating environments free of distractions, and employing regular cognitive training are key strategies supported by research (Gathercole et al., 2019; Diamond & Ling, 2016). Maintaining physical health through proper nutrition, exercise, and adequate sleep, alongside effective stress management, also supports cognitive performance (Blumenthal et al., 2019; Atienza et al., 2018; Walker, 2017).

In examining the New User Experience with Overseas Citizenship of India (OCI) Service, it becomes evident how the highly volatile nature of working memory intersects with the complexity of the application process, leading to potential cognitive challenges for users. The OCI application process, managed by VFS Global, requires individuals to navigate through multiple programs simultaneously, engaging various cognitive processes such as attentional control, information retention, and task switching. However, the limitations of working memory, characterized by its restricted capacity and susceptibility to errors, pose significant hurdles for users attempting to manage the intricacies of the application process. This case study exemplifies how working memory theory can be applied to improve real-world systems through interface redesign and process simplification.

Case Study: New User Experience with [Overseas Citizenship of India \(OCI\) Service](#)

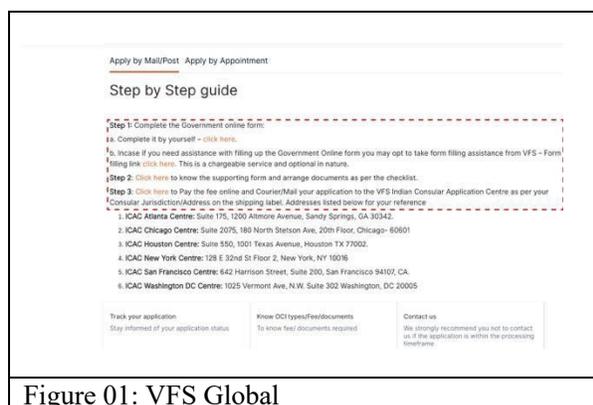


Figure 01: VFS Global



Figure 02: OCI Service

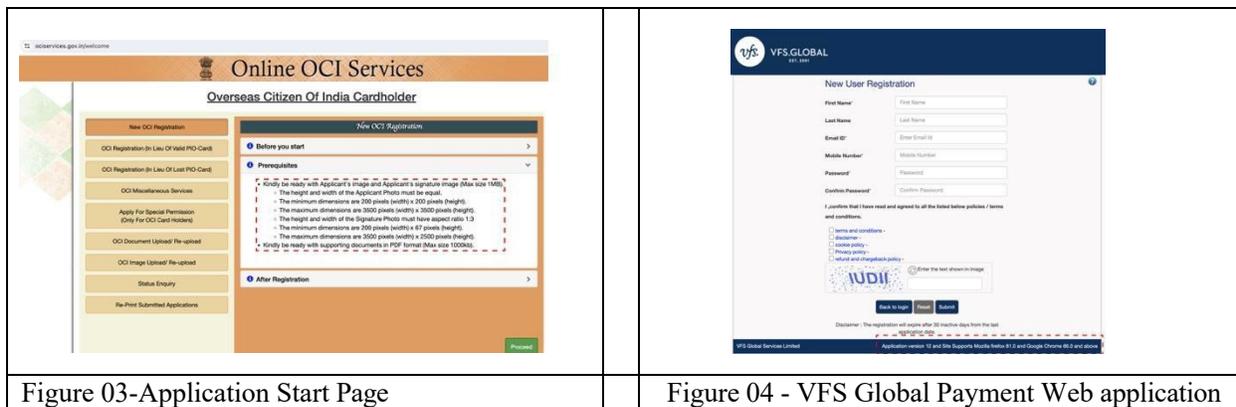


Figure 03-Application Start Page

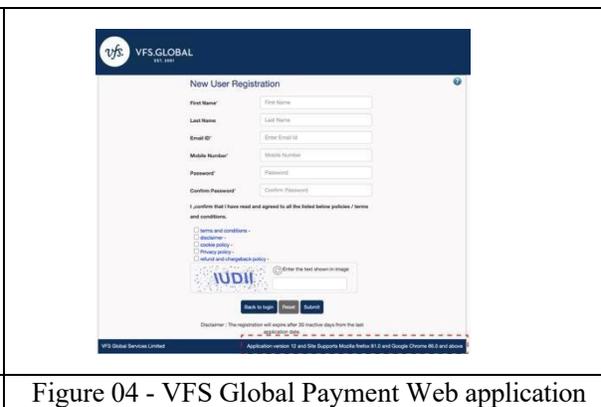


Figure 04 - VFS Global Payment Web application

VFS (Visa Facilitation Services) Global is a facilitator for visa and passport services which manages the application process for OCI services. For this review, I will focus specifically on the document upload interface component of the system, which represents a critical cognitive challenge point for users. The first step is VFS Global Website (Figure 01) where users need to select step 1 to open a new window for Online OCI Service Web application. Before proceeding to the application users need to read the instructions carefully and upload necessary photos, signature and documents. On the OCI service Government website, users then need to select one of the services from the left navigation (Figure 02). Users need to carefully read the guidelines and prerequisites on the right (Figure 03). If the instructions are missed, users will not be able to complete the application. To pay for the service, users must go to the VFS global application (Figure 04). This design is totally different from the first VFS global. Users are required to register here again. A critical issue arises when users encounter technical challenges when filling out the application - they must contact support staff, but after the initial five minutes of complimentary consultation, users incur charges for continued assistance (Figure 03), creating both financial burden and anxiety during an already complicated process.

Let's consider a new user who is an American citizen with Indian origin seeking to obtain OCI status to foster deeper connections with his/her cultural roots and facilitate travel to India for personal and professional reasons. Despite their determination, they experience challenges due to the inherent limitations of working memory, particularly during the document upload phase:

1. Document Upload Interface Challenges: The document upload interface presents specific working memory hurdles that extend beyond general information overload. The interface requires users to:
 - Need to remember precise document specifications (file size limits of 1MB, specific dimensions for photos at 35mm x 35mm, file format requirements of JPG/JPEG) while simultaneously navigating the upload dialog (Sweller, 2011)
 - Maintain awareness of which documents are mandatory versus optional, with unclear visual differentiation between these categories.
 - Track which documents have been successfully uploaded across multiple screens without persistent visual confirmation, taxing visual working memory capacity (Baddeley & Hitch, 1974; Cowan, 2001)

2. **Interface-Related Emotional Impacts:** The document upload interface creates particular emotional stressors that impair working memory function. Users experience:
 - Anxiety when encountering unclear validation feedback after upload attempts
 - Frustration when documents meeting stated specifications are still rejected without clear explanation
 - Uncertainty about whether previously uploaded documents remain in the system when moving between pages
 - Fear of application rejection due to technical document issues rather than eligibility concerns

These emotions directly impact the phonological loop through increased subvocal rehearsal of worries and the central executive through attention division (Okon-Singer et al., 2015).

3. **Specific Recommendations for Document Upload Interface:**
 - Implement document upload preview functionality that shows thumbnails of successfully uploaded documents, reducing visuospatial sketchpad load
 - Provide real-time validation feedback during the upload process rather than after submission, reducing error correction demands
 - Add a persistent "Documents Checklist" sidebar showing completion status with clear visual indicators (checkmarks, progress bar), leveraging the chunking principle (Gobet et al., 2001)
 - Include "Example" buttons for each document type that display correctly formatted samples, utilizing external memory aids to reduce cognitive load

By focusing specifically on improving the document upload interface component, users would experience reduced working memory demands in this critical bottleneck of the application process, potentially improving completion rates and reducing support costs (Chandler & Sweller, 1992; Paas et al., 2003).

Conclusion

In examining the New User Experience with Overseas Citizenship of India (OCI) Service, it becomes evident how the highly volatile nature of working memory intersects with the complexity of the application process, leading to potential cognitive challenges for users. The OCI application process, managed by VFS Global, requires individuals to navigate through multiple programs simultaneously, engaging various cognitive processes such as attentional control, information retention, and task switching. However, the limitations of working memory, characterized by its restricted capacity and susceptibility to errors, pose significant hurdles for users attempting to manage the intricacies of the application process.

Understanding the components and limitations of working memory is paramount, especially when designing user experiences such as the Overseas Citizenship of India (OCI) Service. Designers must be sensitive to the potential cognitive constraints faced by users, including factors like age, disabilities, or attentional disorders. In light of these limitations and considerations, skilled designers employ strategies to optimize user experiences, by using familiar language, managing the quantity of displayed information, minimizing repetition, and directing focus to singular tasks. By implementing these design principles, designers can create an effective and user-friendly product that accommodates the cognitive needs of diverse users, ultimately enhancing the New User Experience with the OCI Service and improving overall user satisfaction.

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