Memory and Emotion
with a case study of Valve Software's "Left 4 Dead"

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Introduction

Memory is the ability of the mind to retain and recall information. It is comprised primarily of three different sections: *sensory* (which prolongs mental representations of stimuli for a short period after we detect them), *working* (a sort of 'mental sandbox' that holds information, formerly known as short term memory and discussed extensively in the following pages), and *long-term* (which stores information over large lengths of time). Of particular interest to us is the *working memory*, which all information that enters long-term memory must first pass through. To use a computer analogy, if the long-term memory is the hard drive, the working memory is the RAM and the processor. All higher-order cognitive operations like metacognition and emotional effects occur here. The issue with working memory is it has an extremely limited capacity. In addition, the information held within decays rapidly if not periodically rehearsed or refreshed in some fashion. In addition, the working memory system is a 'limited resource' system; resources used to maintain or process information are unavailable for other working memory subsystems.

Interference from other sources, negative emotions like anger, fear, and anxiety, can make these limitations even more restrictive. As Calvo (1996) states, "according to the processing efficiency theory, worrying has...a direct interference effect on the cognitive system...and preempts some of the processing and storage resources of the central executive" (p.290).

To maximize the ability of others to use our designs, we must cater to the needs of working memory. With certain techniques, we can expand the duration information can be held, increase the amount of information that can be stored at once, and reduce the effects of outside interference.

Components of Working Memory

Earlier views on memory like the Atkinson-Shiffrin memory model were very simple, viewing what was then 'short term memory' as little more than a storage buffer for the long-term. This model operated on a linear basis; information coming in from the outside world passed through the short term and in to the long term, or decayed away. No provisions were made for separate memory stores based on stimuli type or for two-way information flow between 'short-term' and long term memory (Atkinson & Shiffrin, 1968).

Baddeley (1998) noted that "this model encountered problems both in terms of its assumptions regarding learning and the impact of neuropsychological damage to the [short term store]. If the STS [short term store] served as a unitary working memory, then patients with STS impairment should show little capacity for long-term learning or for everyday cognitive activities" (p.830). These patients were located, but had few impairments beyond their lack of short-term memory storage, showing that working memory is more complex than just a short-term buffer.

In 1986, acknowledging problems with existing memory models, Baddeley proposed a model of short-term memory that relied on three components, "a central executive and two storage systems: the phonological loop and the visuospatial sketchpad" (Baddeley, 1998, p.829). This *working memory* system sits between our perceptual and long-term cognitive systems, providing us with a means to act on and manipulate information. A third storage system, the *episodic buffer,* was proposed by Baddeley in 2000 and will be discussed here as well.

Central executive

The central executive manages “the control of behavior by habit patterns or schemas, implicitly guided by cues provided by the environment,” (Baddeley, 1998, p.835) and takes control from these patterns when attention is required. It also supervises its two storage subsystems and controls the flow of information to and from each. Effectively, the central executive is a ‘process manager’ that handles information flows, the application of items in our ‘cognitive toolboxes’ (like different learning techniques, etc), and the monitoring of automated and mindless tasks. Robbins et. al (1996) noted in their study of chess players that the central executive appeared to handle “the selection of candidate moves and the evaluation of particular outcomes,” (p.88), implying that one of its primary functions is to *act* on collected information.

Phonological loop

Each of the storage systems focuses on a particular sort of stimulus. The *phonological loop* “is specialized for the retention of verbal information over short periods of time; it comprises both a phonological store, which holds information in phonological form, and a rehearsal process, which serves to maintain decaying representations in the phonological store” (Baddeley et al, 1998, p.158). The store maintains phonological information in the proper sequence (sounds strung together to form words, as an example), while the process essentially repeats the store’s information repeatedly (hence, the “phonological loop”) to prevent decay.

The loop also stores written language, which through the process of silent articulation is converted into auditory information. Burgess and Hitch (1999) note that “the phonological loop is capable of explaining...various aspects of verbal short-term memory performance...and has proven successful in explaining new findings...[like the observation that] variations in memory span across languages can be predicted from...speech rates” (p.552).

Visuospatial sketchpad

The *visuospatial sketchpad* holds information pertaining to what we can see and is split into two sub-components, the *visual* component that deals directly with form, color, shape, and other visual characteristics and the *spatial* component, which handles physical manipulation and planning (like how to rotate a puzzle piece to fit in with a selection of other pieces). There is evidence indicating that the sketchpad connects with both the perceptual areas of the mind responsible for taking in visual stimuli from our environments and ‘imagery generation’ where the things we see in our ‘mind’s eye’ are created and stored. Logie (1995) notes that when participants were asked to rely on a visual mnemonic (an imagery task) to recall certain words and shown various nonsense patterns (the processing of which is a perceptual task), “The results were clear. When subjects were asked to use the visual mnemonic, concurrent irrelevant patterns disrupted recall” (p.74).

Episodic buffer

The *episodic buffer* is “a limited capacity system that...is capable of integrating information from a range of sources into a single complex structure or episode. It is a buffer in the sense of acting as an intermediary between the subsystems which use different codes, combining them into a unitary multi-dimensional representation” (Baddeley & Wilson, 2002, p.1738). Added to Baddeley’s model in 2000, the buffer is Baddeley and Wilson’s attempt at addressing some earlier criticisms leveled at the 1986 version of the working memory model stating that it was never explained how information from various sources was actually integrated in working memory. The buffer provides a way to integrate information from the phonological loop and the visuospatial sketchpad, along with stimuli coming in from the outside world and long-term memory. To use another real-world mapping, take the idea of a movie. A movie combines a video track with an accompanying audio track to create an integrated experience. If the phonological provides the audio and the visuospatial sketchpad provides visual and spatial information, the episodic buffer is the ‘mixer’ that integrates these inputs in to a single representation.

Cognitive Load and Limitations of Working Memory

While powerful in that it grants us the ability to integrate information coming in from the outside world with that which we already know, the working memory system has limited storage and duration potential, and is susceptible to external and internal interference. The combined effects of capacity, duration, and volatility are known as *cognitive load*.

Capacity of working memory

The capacity of one’s working memory is determined by a number of factors. Age, emotions, expertise, and motivation all play a role in affecting cognitive load, and in turn, capacity. Just & Carpenter (2002) note that there is a “trading relation” between storage and processing; the more processing being done in working memory, the less information we can store before affecting performance and vice versa (p.123). The amount of overall capacity one has can vary substantially from individual to individual as well. Despite this, a point of reference can be useful. Recent research has indicated that on average, we can store about 4 ‘chunks’ or intelligent groupings of information at a given time:

- Luck and Vogel (1997) state that the visuospatial sketchpad “stores integrated objects rather than individual features” (p.1) and that we can hold about 4 objects, each with four distinguishing features, at a time
- Cowan (2001) notes that there is a substantial body of research (at least 25 independent studies) pointing to a “capacity limit of about four items” (p.90) where working memory is concerned. In this instance, an item refers to a ‘chunk’, or “a collection of concepts that have strong associations to one another and much weaker associations to other chunks concurrently in use” (p.89).

These are not concrete numbers; various other factors can affect one’s working memory capacity. Wingfield et al (1988) noted that as we age, our working memory capacity decreases. In studies conducted with young and elderly participants, Wingfield noted a small gap in simple word span performance (attempting to recall the last word of each sentence in a list) and a significant gap in loaded word span performance (attempting to recall the last word of each sentence in a list while *also* performing a comprehension task) between the two groups. Elderly participants consistently performed worse than their younger counterparts (p.104). It would seem that as we get older, the amount of cognitive resources available in the shared WM pool decreases, resulting in diminished capacity.

Expertise and knowledge of the observed subject matter plays a large role in the load placed on working memory. Kalyuga et al (2003) "call the reversal of [negative] cognitive load effects with expertise the *expertise reversal effect*" (p.23). The team describes the effect as follows: When informational elements are shown in a particular fashion, experts can treat all of the elements as a chunk of information. In working memory, a single chunk of information requires less cognitive resources than maintaining and processing multiple lower-level packets of information, thus reducing the load of working memory. Because they practice and constantly use schemas for organizing information in to chunks, experts can rely on the central executive (being the manager of automated tasks and schemas) to automate the task of transforming the low-level information into a higher-level chunk to begin with. This further reduces cognitive load, as automated tasks require much fewer resources than attentionally-driven, 'manual' tasks. (Kalyuga et al, 2003, p.24).

Duration and volatility of working memory

The duration of any information in working memory is extremely limited; without rehearsal, stored information decays rapidly. As seen with the *articulatory suppression effect*, participants prevented from reciting items have vastly reduced recall performance (Baddeley, 2000, p.419). This volatility (and hence, any given element's duration in working memory) is dependent on three major factors: similarity of the information to other elements of information being concurrently held, where our attention is directed (essentially, if we are rehearsing), and how similar each element is from a visual or verbal/auditorial perspective.

The more similar a given element of information is to another being concurrently held, the more difficult it is to remember. An example of this occurs in the phonological loop, where items that are "similar in sound are harder to remember accurately" (Baddeley, 2000, p.419). This is known as the *phonological similarity effect*. A related effect occurs when information being stored is mostly of a specific type (visual or auditorial). Yaghoub Mousavi et al (1995), in their study of three groups of geometry students working on problems presented in auditory form, verbal form, or auditory **and** verbal form, noted that "a mixed mode of presentation proved superior...supporting the suggestion that working memory capacity was increased by a dual-presentation mode" (p.332). When problem information was presented in a single format, student performance was lower than when information was presented in both formats. This indicates two things. One is that certain types of information can be represented more accurately in one form or another (depending on the individual). The other is that the benefits of these split representations outweigh the drawbacks imposed by having to integrate the two forms of information through the episodic buffer. Information presented in a more suitable form appears to occupy less cognitive resources. This due to the limited capacities of each of the sub-storage systems in working memory, the phonological loop and the visuospatial sketchpad. The load imposed by trying to sort and integrate from one ‘overloaded’ store is higher than the effort needed to integrate a more manageable amount of information from two separate stores.

Emotion and its Effects on Working Memory

Positive emotions

Positive emotions can allow one to overcome certain limitations in working memory. Gray (2001) notes that in an approach state (how sensitive we are to reward, generally increased by positive emotions) “verbal performance [in working memory tasks] was enhanced” (p.442). Interestingly, spatial performance was impaired when participants were in an approach state (Gray, 2001, p.442). This implies that the particular types of cognitive processes experience enhanced or diminished performance based on current emotions. Gray contends that this could be because certain aspects of cognition are linked; perhaps spatial control processing is directly connected to states of withdrawal (monitoring for threats) and verbal processing is directly connected to states of approach (monitoring for reward).

Negative emotions

Eysenck et al (2007) explain that negative emotions, especially anxiety, have a profound impact on cognitive processing performance. In stressful conditions, we begin to worry. This has two primary effects of working memory. First, the presence of the anxiety and worrisome thoughts consumes available cognitive resources, so fewer are available for task and information processing. Second, the increased motivation to minimize one’s state of anxiety consumes further resources by redirecting resources away from our current task (p.337). With a diminished pool of resources, cognitive load increases and performance decreases. Because the main effects of worry “are on the cognitive executive...anxiety’s adverse effects on performance and efficiency should be greater on tasks imposing substantial demands on...processing and storage” (Eysenck et al, 2007, p.337).

Miller and Bichel (2004) further note that because “high trait anxiety individuals employ more resources in completing a task in order to maintain the same level of accuracy as low trait anxiety individuals,” (p.593) they experience diminished performance and increased task times. However, this is not to say that a small amount of anxiety cannot improve performance. Miller and Bichel (2004) were surprised to find “that a low level of performance was also observed in low trait anxiety individuals in the low state anxiety condition. Individuals with intermediate levels of arousal (low trait anxiety subjects in the high state anxiety condition and high trait anxiety subjects in the low state anxiety condition) experienced the best performance” (p.593). It would seem that anxiety plays some role in cognitive engagement:

- Low levels of anxiety correspond with low levels of arousal; it seems that working memory resources are not “invested” as heavily in low arousal tasks because there is little incentive to engage in them.
- High levels of anxiety take away valuable resources and increase cognitive load, making it more difficult to perform tasks and process information.

- A ‘medium’ level of anxiety provides the motivation to engage in a task without draining cognitive resources away.

The last three points are particularly important when discussing video games. There are times when one may want to passively engage in a casual game, and a low level of anxiety would be appropriate there. In something more competitive or time-limited, a medium level of anxiety is appropriate to focus one’s attention on a task without impairing performance. A high level of anxiety (generally speaking) would be undesirable, as it creates a large amount of cognitive load, resulting in frustration and a lack of enjoyment. With this in mind, let us examine some of the elements in Valve Software’s “Left 4 Dead” that serve to regulate anxiety levels and maximize the ability of working memory to integrate information, all while preserving a “horror” atmosphere.

Case Study: Valve Software's "Left 4 Dead"

"Left 4 Dead" is a cooperative first-person shooter video game created by Valve Software, set two weeks after an unknown pathogen has turned most of the world's population in to zombies. The game has a team of four human-controller survivors attempting to reach a rescue point while an opposing team of computer-controlled zombies attempts to stop them. The setting is understandably dark and relies heavily on horror elements for atmospheric and cinematic purposes. The anxiety this setting creates is in direct competition with the cooperative elements of the title; players need to work together to survive, helping each other out of dangerous situations and paying keen attention to their environment. Similar to what Miller and Bichel (2004) observed in their studies on levels of anxiety and performance, if anxiety levels are too low, players will be bored and not engage with the game. If anxiety levels become too high, performance decreases due to increased working memory load and players may become frustrated. Effective monitoring of anxiety levels during gameplay helps create the most fun experience for the players.

Initially, the title had a large number of issues with players experiencing high levels of anxiety. In the game's commentary, the developers explained that players were having difficulty keeping track of their teammates, especially in dangerous situations where one teammate would be incapacitated or threatened. There were no on-screen visual indicators or auditory cues present to alert players of these situations. With so much happening visually on (and off) screen at once, if you failed to see your teammate get tackled, you had no way of knowing he was in trouble. Since players can only survive for a few seconds in an "incapacitated state" without assistance, this resulted in a large number of situations where players who were not helped by their teammates were eliminated early on in each level. This generated a sort of cascading anxiety effect:

- Already in a 'dangerous' situation, survivor teams now had to complete the level with fewer individuals helping. The impact of every poor decision was now increased, imposing additional stress on the players.
- The players who were eliminated early on (because their teammates never knew they needed help) became anxious and frustrated themselves. They would often project this frustration on to their still-living teammates, who would in turn become more anxious
- The increased levels of anxiety would reach a point where they impacted performance, often causing additional teammates to be eliminated
- The end result was that that teams of survivors rarely completed any levels and did not enjoy playing the game.

The question arose: what to do to help manage anxiety without destroying the sense of atmosphere that defines the title? The Valve team made a few large additions to the game that cater to both the visual and the auditory components of working memory. This is important, as Yaghoub Mousavi et al (1995) noted that in their experiments with performance and content presentation, "a mixed mode of presentation proved superior...supporting the suggestion that working memory capacity was increased by a dual-presentation mode" (p.332). When in a situation where one stimulus may not stay in working memory long enough to have an impact, the presentation of the same information across different channels can be an effective solution.

The Issues and How They Were Addressed

Visual

One of the primary problems with maintaining situational awareness (important for information processing in this case) in early versions of the game was that player characters did not stand out from the environment at all. This made it difficult to monitor your teammates and determine their locations (important when staying together may mean the difference between success and failure).

Early character designs

Revised character models

The redesigned character models were brighter and sharper, standing out from their environments more prominently than before. In addition, brightly colored auras or outlines were added to character silhouettes that could be viewed through walls and floors. A solid blue outline indicates safety, while flashing green means in danger. The HUD/status area at the bottom of the screen for each player was also tweaked to flash slowly when that person was in danger.

Because of these additions, the models' chances of being picked up by the senses and making their way into the visuospatial sketchpad were increased. Players could free up cognitive resources formerly spent looking for their companions for use on other tasks, like determining the best route to reach a particular location or actually saving a distressed friend.

Phonological

In addition to visual cues, some auditory enhancements were made as well. Survivors automatically speak relevant dialogue when certain events occur, like being pounced by a zombie or after locating supplies (pain pills, weapons, first-aid kits, etc.) This helped to reinforce an existing visual indicator (in the case of being pounced) or to convey information that was formerly not conveyed at all (in the case of locating supplies).

In addition, extra audio cues were provided to help convey dramatic tension and give players a small "head-start" or "alert" on an upcoming situation. For example, the background music swells, the tempo increases, and finally changes over to a sort of "dramatic, rushed, dangerous" theme when a swarm of enemy zombies is about to attack. Survivors also make comments about upcoming events, shouting "Here they come!" right before a horde arrives. The special zombies also gained characteristic noises; each type, formerly identified by shape alone, was now easily identifiable by a particular growl or gurgle. This also had the benefit of alerting players to their presence *before* a visual confirmation was made.

Cognitive/central executive and learning

In an effort to work towards reducing cognitive load for new players, allowing them to quickly pick up game mechanics and develop expertise, a tutorial/monitoring system was developed. Whenever players perform a positive (taking out a first aid kit and looking at a wounded survivor) or negative action (setting off a car alarm and attracting zombies), they receive immediate feedback about their actions. When the player demonstrates to the monitoring system that he or she has "learned" that particular lesson, the messages stop appearing. This relates back to automated tasks requiring much fewer cognitive resources than attentionally-driven, 'manual' tasks, as noted by Kalyuga et al (2003). Once it is demonstrated that red, beeping cars set off alarms if you approach them, one eventually builds an automatic avoidance system (a schema). This schema requires far fewer resources to use than actively searching for and avoiding red, beeping cars.

The culmination of all of these changes was the introduction of an artificially intelligent "director" in to Left 4 Dead that monitors player health, ammunition, status, and general anxiety levels (how fast people are firing their weapons, etc.). When the system detects that players are doing fairly well, it increases the difficulty of the game. When the system notes that players are likely to be stressed and anxious, it eases up.

In practice, this system works extremely well. Through my hours of playing, the title seemed fairly good at gauging our stress levels. Whenever the thought of "a break would be really great right about now" would come in to my head, I would find a safe room with some equipment, or I wouldn't see any enemies for a solid 30 or 45 seconds.

The opposite was true as well; just when you'd begin to feel a little bored, some event would occur to draw your attention back in.

In the end, Left 4 Dead does an admirable job of managing anxiety levels, keeping players in a state of engagement while avoiding performance reduction due to an abundance of cognitive load. The use of multiple channels to convey information helps improve the duration of said information in the phonological loop and visiospatial sketchpad, allowing it to be used by the central executive to make better decisions regarding gameplay. In addition, the use of a monitoring system for both learning (to further reduce load through the use of schemas) and anxiety management is essentially unprecedented in this particular medium. Other developers should take notice of these advancements in adaptive difficulty, as they translate directly into an improved recreational experience.

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