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Chapter 3
Development of a Memory Training Game

Kristoffer Jensen and Andrea Valente

Abstract This paper presents Megame *[me-ga-me]*, a multiplatform game for working memory training and assessment. Megame uses letters and words to amuse, train and assess memory capacity. Based on memory research, the main parameters of the working memory have been identified and some improvement possibilities are presented. While it is not clear that the working memory in itself can be improved, other cognitive functions are identified that may be improved while playing Megame. Other uses of Megame include spelling and vocabulary training and learning modality assessment. Megame is written in Python using an agile and iterative approach, taking advantage from rapid prototyping and allowing for user-driven development.

Keywords Memory · Learning · Attention · Interference · Game

3.1 Introduction

Memory is a central component of cognition and thinking in general. According to Baddeley [1] reasoning, comprehension, and learning capacity are all correlated with the capacity of the short-term memory. The concept of short-term memory is now largely superseded by that of the working memory, active in all aspects of memory, the encoding, storage and retrieval. For instance, the working memory is active in the consolidation process, at least when actively thinking about the information being consolidated. It is therefore of importance to utilize ones

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memory in the best possible way. While it is not clear that one can improve the memory using memory-training methods [2], many general brain and memory enhancement games exists. Still, some of the games may be fun to play, and at least allow improvement in tasks related to the game played. In addition specific elements related to memory, such as attention, interference, chunking etc. can be supported, stimulated or trained by playing simple games. We present here an approach to such a game, with a focus on training the working memory while directly estimating its capacity, thus motivating the player to improve the memory while playing.

The game itself is inspired by classic memory games, like *memory*,[1] and we envision it as a single-player, multi-platform game. The gameplay is simple: various symbols, images or shapes are presented to the player, then hidden; the player has to remember them later, while composing a sequence (of letters for example). Megame has many configurable parameters, for instance we design it so that we are able to increase the number of letters, and in that way assessing the limit with respect to the number of elements in working memory. Memory capacity assessment is the central goal of the Megame game but other uses are also envisioned. Finally, it is not our goal to create an addictive game, but rather a good occasional challenge that can be used for players' self-assessment and that will provide us with a tool for testing different memory models.

This chapter is organized as follow, Sect. 3.2 presents the main theories on memory, in particular the working memory, and the relationships of importance between this memory and learning, attention and memory assessment. Section 3.3 presents the design and development of Megame, with details of the two versions of the game and the parameters that can be changed when changing level in the game, and the details of the feedback on the memory capacity. Section 3.3 also covers the software development methodology. In Sect. 3.4 different uses and settings are shown to be of interest for scientific experimentation about the memory and related areas, and the chapter ends with a conclusion.

3.2 Memory

The processes involved in memory are encoding, storing and retrieving information, and this processing of information may be considered to be central to cognition [1]. Memory is considered to take place in three stages [3], the initial sensory memory of span up to 300 ms approximately, the working memory with a span of a few seconds and up to a minute using attention, and the long-term memory (LTM) with a time span of years. The sensory store and the working memory are modality-specific, which means that they treat in particular visual, auditory and touch

1 http://en.wikipedia.org/wiki/Concentration_(game).

independently. This may have implications for Megame, and future work include using items in different modalities, in order to train and assess these.

3.2.1 History of Memory Ideas

Memory is today very related to information and we take for granted that machines can remember and find data for us. However, as discussed in Rose [4] remembering was a complex and central skill in pre-writing societies. Some professions developed techniques for enhancing individual's memory: for instance poets could memorize entire epic poems by re-structuring them into rimes, using a certain *metre*, and by the means of singing. Writing as a form of external, persistent memory was opposed by great figures like Socrates (for whom we know through the writings of Plato), since:

> Writing destroys memory and weakens the mind, relieving it of work that makes it strong. Writing is an inhuman thing.[2]

However, apart from poets, other ancient professions required memorization of long presentations and arguments, lawyers for instance. Therefore, various mnemotechnic methods were devised; an example is the *method of loci* described by Cicero in his *De Oratore*.[3] Its key idea is to remember unstructured information by association with specific physical locations or objects in a room. The person that wants to memorize the items can, for example, visualize a room that is familiar to her (or a fictitious room) and associate a word or an item to each object in that room. To remember, one takes a mental tour of the room and retrieve words by association with the objects that are encountered. Other memorization techniques suggest the creation of a story, where the details of the narrative help recalling items.

These and many other memorization techniques, described throughout antiquity and the middle ages,[4] show that memory was always considered something that need to be trained and that assumption is clearly that memory can be improved following the right methods.

3.2.2 Memory Overview

It is clear that any interaction, such as Megame, that does not involve all modalities in the early memory systems, will not have an influence on all parts of

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[2] In *Phaedrus*, Plato, around 500 B.C.

[3] Literally "On the Orator", written circa 55 B.C.

[4] As in *Ars Memoriae* ("The Art of Memory") by Giordano Bruno, 1582.

the working memory. It is interesting in this context to determine the principal target group of the game. This can be done, for instance, by looking at the use for dyslexic children, or by choosing the target group using a questionnaire, such as the VARK questionnaire [5]. In the VARK model, learning is supposed to use one modality principally, Visual, Aural, Read/write or Kinesthetic. As a large part of learning in schools take place in the read/write category, children with less preference for this modality benefit from activities, such as playing Megame, that strengthens the preference for reading and writing.

While Megame mainly regards the working memory, the identification/recognition of correct word is related to the long-term memory and other cognitive skills. In general, the working memory can be said to be active in all three memory processes, as it is central in the encoding stage, where each new information element is temporarily stored, but also active in the other stages, as information stored or retrieved necessarily passes through the working memory. Thus, improvement of the working memory is bound to be beneficial to all aspects of memory, and thus of cognition in general. The proposed game is also likely to be influential in increasing the vocabulary due to the generation effect [6], that states that information that is generated, such as the words to be created from the letters in Megame, is better memorized.

While the game remains in the letter/word category, no serious issues should arise from the complicated level of representation processing [3]. This processing enables us to remember the meaning of information (that resides in higher levels of processing), while forgetting the exact wording that resides of lower levels. This occurs, for instance, when you read something and the say it in different wording. The information has passes to a higher level of processing, where the meaning, and not the wording is central, and then back again to be said out loud. Assumingly, there is no such level of representation in spelling, as this is an exact, deterministic process.

If the target word is visible, the player does not need any cues. However, if the target word is hidden, the results may be dependent on the player's ability to cue the correct word. Cueing or priming is a common process in memory retrieving, but it is not believed to be of strong relevance in these games, that is regarding letters only in this phase of development. Still priming [7] is seen as a potential means of increasing or affecting the difficulty of the game.

The two main factors that influence memory seem to be attention, which increases the time the information remains in the memory (by increasing the activation strength of the element under attention), and interference that weakens the activation strength of the information due to conflicting memory traces. Without attention, memory weakens within a minute, and it is believed that the development of attention combined with efficient coding schemes are the main possible memory enhancement. Better and more efficient encoding reduce interference, as new information is placed at proximity to relevant but not interfering information. However, Wixted [8] resumes the research on forgetting (which may take place at the time of encoding, or at the time of retrieval), and advances the role of the limited capacity of the brain, that induces retroactive interference, i.e.

that new memory encoding taking place after the first memory will interference with the consolidation process of this memory trace. This would also explain why sleep and drugs are helpful in retrieving memory traces, and it could be explaining the use of power-naps, and other structured methods of relaxation within e.g. mediation. Another different aspect of memory is chunking [9]. For instance, the capacity of reading involves chunking, as the letters that constitute a word are chunked into that word in the cognitive processes.

Memory traces are stored through consolidation [10] and also through repetitions. Consolidation consist of an initial synaptic stage that takes place within minutes and up to a few hours, and the system consolidation that takes place within weeks up to years. After the synaptic stage, the memory trace is resistant to interference. After the system consolidation, the information trace is no longer bound to the main memory cortical part, the hippocampus. Consolidation occurs when information is repeated. Repetitions can be either massed or distributed, and according to Glenberg and Lehmann [11], distributed repetitions are more efficient in memory recall. This is generally called the spacing effect.

3.2.3 Memory Assessments

Megame can assess the capacity of the working memory of the participant. In order to do so, the model presented in Jensen [12] is used. This model considers two components of the working memory: the number of elements, and the duration of each element. The activation strength of the working memory is decaying exponentially with the number of elements, $A_n = 1 - ln(N + 1)$, and with the duration of the element, $A_t = 1 - ln(t + 1)$. The total activation strength is $A = A_n + A_t$. In that way, the model can either contain many elements for a short time, or few elements a long time, as shown in Fig. 3.1. When the activation strength of an element becomes negative, $A < 0$, the element is purged from memory.

Another aspect where attention comes into play is the serial position effect, where earlier elements, which potentially have received more repetitions and thus entered the realms of the long term memory, are better remembered than the middle elements. It does not seem to be a problem in our game, as obviously the earlier letters may receive more attention and rehearsals, but it must be understood that these letters are already present in the long term memory (at least for everybody except very young children), and it does not affect the assessment of the memory capacity to any degree.

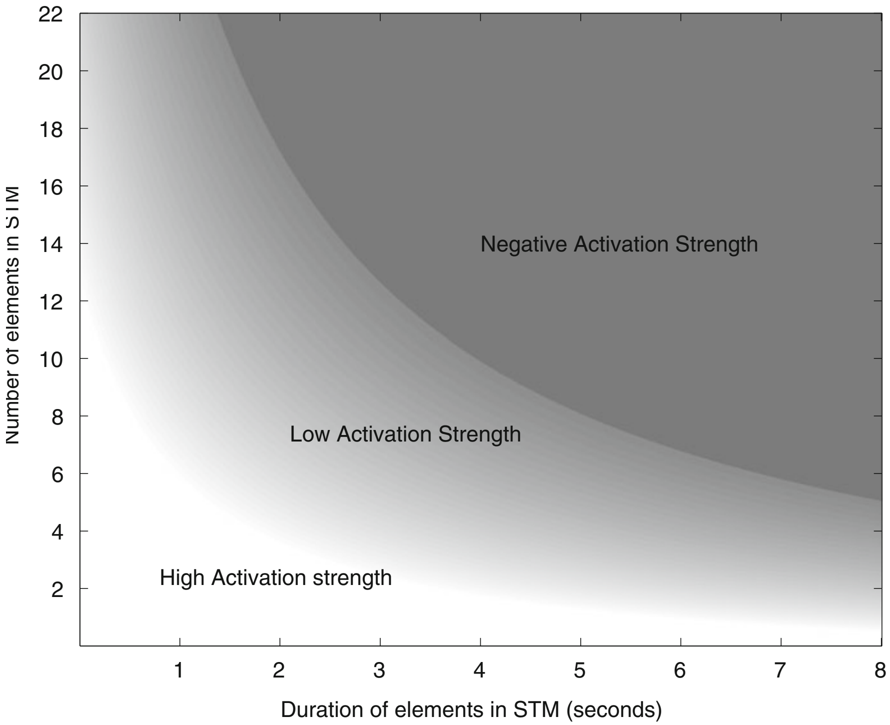

Fig. 3.1 Activation strength as a function of duration and number of elements. Elements are purged when activation strength is negative (*dark grey area*). (From [20])

3.2.4 Memory and Games

Many games have been developed with relations to improving the memory capacity. Here should be mentioned the popular Memory game,[5] and Kim's Game[6] which enables children (and others) alone or together to improve their concentration, by trying to remember where the cards are in order to form pairs and guess the content of a hidden object collection. Other popular memory games include the electronic Simon[7] in which the gameplay include listening and watching to a sequence of notes and corresponding colored lights, and then reproducing the sequence on the buttons in the same position as the light and

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[5] Memory, also known as Concentration or Pairs can be played with a standard deck of playing cards or with special decks. Source: http://en.wikipedia.org/wiki/Concentration_(game).

[6] This game is described in *Kim* by Rudyard Kipling, 1901, in Chap. 9. The book is freely available at Project Gutenberg (http://www.gutenberg.org/files/2226/2226-h/2226-h.htm).

[7] http://www.accessmylibrary.com/coms2/summary_0286-18399548_ITM.

sound. These games were designed to depend on good memory skills in order to succeed. Many brain development and trainer computer games have also been developed, for example for the Nintendo DS console, such as the Nintendo's Brain age[8] and *The Professor's Brain Trainer: Memory.*[9] Today, companies such as CogMed,[10] Lumocity,[11] and many others, including game and platform developers, introduce programs via games and internet, and also propose programs in schools and workplaces.

It is clear that in general, people learn more when they get older, but it is not sure they learn better. This is what is termed crystalized and fluid intelligence [13]. While previous studies has shown improvement in memory when performing tasks that supposedly improve the working memory, recent studies [14] and meta-studies [2] has shown that this is mainly an effect of learning the task and that the working memory capacity does not improve, nor is it clear that any transfer of improvements to other tasks occur.

This aspect of far-transfer, here meaning to be able to use the improvement in cognitive skills in daily life is important to keep in mind, when designing the flow [15] of the game. Therefore, in the level design of Megame we take an ethical standpoint in order to ensure that the flow element is not too addictive; crippling flow would simply require tuning the rate of increase in difficulty throughout the levels.

An interesting, and perhaps counter-intuitive argument can be made about the role of repetition and acquisition of perceptual patterns. In [16] the mind in general is discussed as:

> The mind is not a machine, however, but a special environment which allows information to organize itself into patterns. This self-organizing, self-maximizing, memory system is very good at creating patterns and that is the effectiveness of mind.

Thinking in patterns can however hinder creativity (according to de Bono, who is interested in creative thinking, problem solving and lateral thinking). This extends also to memory and in particular visual memory and painting [17], where methods are devised to break habits and re-learn how to "see". All this points to memory plasticity and to the possibility that exercise, play and memory techniques can effectively alter (in a positive or negative sense) one's skills in memorization and perception of patterns. Therefore we are aware of the importance of testing our game in responsible ways.

Finally, it is not our goal to create a strongly addictive game, but rather a good occasional challenge that players can use for self-assessment and that will provide a tool for testing various models and assumptions about memory.

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8 http://www.nintendo.com/games/detail/Y9QLGBWxkmRRzsQEQtvqGqZ63_CjS_9F.

9 http://www.amazon.co.uk/The-Professors-Brain-Trainer-Nintendo/dp/B000LITROQ.

10 http://www.cogmed.com/.

11 http://www.lumosity.com/.

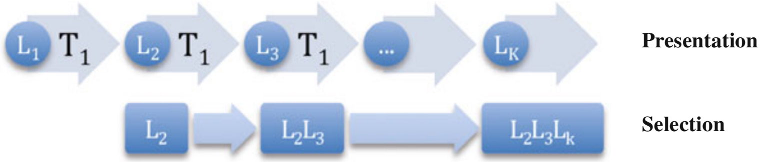

Fig. 3.2 Gameplay of HTW version of game. Once selection is done, success or failure can affect the level characteristics

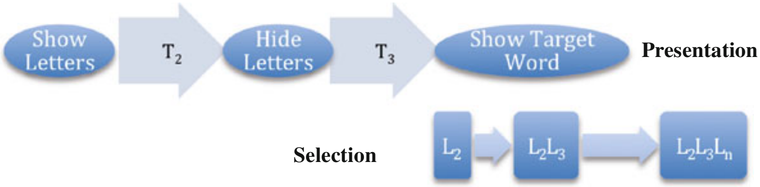

Fig. 3.3 Gameplay for the VTW version of the game

3.3 Game Design and Development

There currently exist two gameplays in Megame. One version, the Hidden Target Word (HTW) version Fig. 3.2 presents a number of letters one after one, with a brief pause between each letter. After each letter is presented, it is hidden, and the player should remember it. The goal is to form a word of a given number of letters out of a subset of the presented letters. This is done by clicking at the letters one by one, in the correct order, which can be done after any letter, assuming enough letters exist to form the word. If the word is formed correctly, the player may continue and the level difficulty may increase. The second version, the Visible Target Word (VTW) version Fig. 3.3, first presents all letters for a brief moment. When the time is out, all letters are turned upside down, hiding the letters. After another brief moment, the target word is presented, and the player should click on the letters of the target word, in the correct order, in order to win the game.

The gameplay is very simple, consisting of two stages, the presentation stage, and the selection stage. There is a pause after the letters are shown (for T_2 s), and another pause before the target word is shown (T_3 s); the time between to letters are shown is T_1 s, and all three time parameters, T_1, T_2 and T_3, can be 0.

If the target word is hidden, it is difficult to identify other modalities that could create true sequences distinguishable from other false sequences. Only words are such sequences for non-experts. On the contrary, if the target word is visible, then it is possible to use other presentation modalities, such as sequences of colours, shapes, sounds etc. It is also possible to present nonsense words.

3.3.1 Levels

Megame permits the modification of the difficulty level, through several means. Because of the delays between presentation of letters (T_1), and between letter presentation and hiding (T_2), and presentation of target word (T_3), there is a possibility to change the level difficulty while at the same time measuring the duration of the players working memory.

The changes in the letters that relates to level difficulty include the number of letters in the target word (N), the number of letters on the table (K). K must be equal or larger than N (unless letters are repeated in the target word), since the target word needs N letters. The difficulty is believed to be related to the additional unused letters ($M = K–N$), that interferes with the choice of the target word letters. Therefore, increasing M increases the difficulty.

If the table contains several copies of the same letter there could be two effects, either it becomes easier, because there are several possibilities to find the target letter, or it becomes confusing, because you loose the localization of the letter, since it exists in several locations. It is also possible to alter the order of the target word on the table, by simple inversions, mirroring (backwards), circular shifting, and scramble all letters except the first and the last.

3.3.2 Development

We decided to develop our game in Python, following an agile and iterative approach. Python is a very good language for rapid prototyping and coupled with the pygame library, it offers great productivity. As soon as the specification of the Megame was in place, it was possible to quickly design a mock-up of the game (visible in Fig. 3.4). We used Pygame, a widely adopted python graphic library based on SDL[12]; the adoption of Python and Pygame makes our scripts simple to write and highly portable, since standard implementations of both language and library are available for the most common operating systems (including Windows, Mac OS and Linux).

Moreover, Python runs on Android devices (see Fig. 3.5): as discussed in [18], detailing the Scripting Layer for Android (SL4A), a python applications can be developed on a laptop, then transferred to an Android device where a local Python interpreter will run it. The main problem running Python on tablet and similar devices is that all the Android-specific services are usually accessed via a Java Virtual Machine: the solution employed by SL4A is to setup remote communication between the Python runtime and the Java runtime, using remote procedure calls (RPCs) and JSON-based serialization[13] to exchange data back and forth

[12] Single Directmedia Layer—http://www.libsdl.org/.

[13] JavaScript Object Notation—http://www.json.org/.

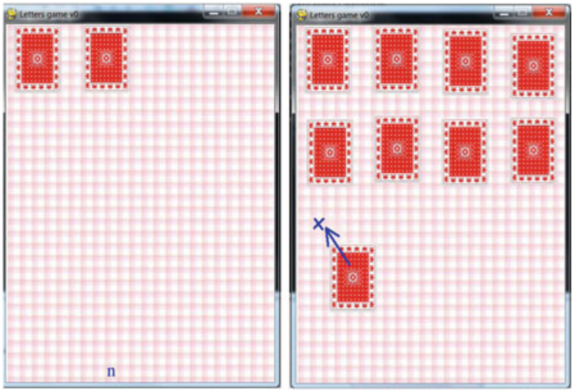

Fig. 3.4 - Version 0 of Megame. On the *left* the letters visible at the *bottom* of the application window, turn into a card one by one. The card will move (*face down*) towards its position in the main (*central*) area of the window. The player can click instead on a card to turn it. On the *right* further on in the game, a card moving towards its final position (the *blue* "x")

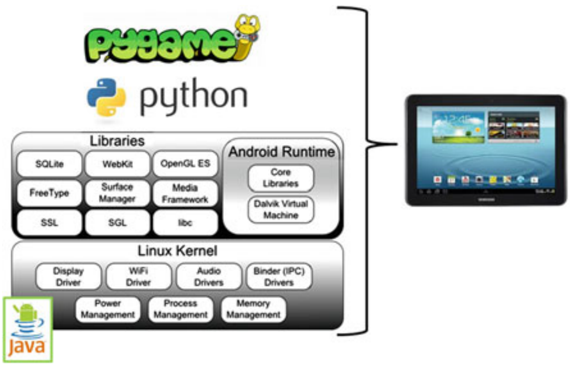

Fig. 3.5 Python running on Android. Python runs on *top* of the linux kernel, and it uses standard libraries. The main complication is that most of the Android-specific API are available only through Java and the Dalvik virtual machine (special Java virtual machine present on Android)

between the 2 runtimes. Thanks to this mechanism it is very simple to, for example, read the state of the accelerometers onboard an Android tablet, and use them in a Python script.

The SL4A does not contain a porting of the Pygame library, but another project is under development, that ports a significant portion of Pygame in Android: PGS4A.[14] Using this partial porting of Pygame, it is possible to develop a standard Python Pygame application, using (for instance) the mouse as main input device; the application would run (and can partially be debugged) on the laptop or stationary machine where it was developed. The application can further be packaged, signed and transferred to an Android device, where it can run and re-map touch gestures to work as mouse events.

This is perhaps the closest Python development can get today to seamless application deployment on Android. Taking advantage of SL4A and PGS4A we are able to rapidly design, run and test our game prototypes on Windows, Macintosh and Linux machines, as well as on portable devices. This way of

[14] Pygame Subset for Android—http://pygame.renpy.org/.

Fig. 3.6 The application is given to multiple users, each playing single-player sessions at Megame. The data can be stored locally on the Android device, then periodically the device will communicate to a central server (managed by the authors) and download player statistics and progress

working allows for the creation of multiple versions of the game within the same hour, and it provides functional prototypes that could support early user testing.

Both implementations, PC and Android device, save player statistics on the local machine (see Fig. 3.6); periodically the statistics are also transferred on a central server, administered by the authors. This makes data collection quite simple, and enables players to use the game for memory capacity assessment. In future versions the game can easily be extended with an occasional/asynchronous multiplayer mode, allowing players to engage in tournaments. Social gaming can be supported by the addition of shared high-score boards, hence providing more extrinsic motivation to players.

3.4 Scientific Uses

While the literature does not seem to favor the possibility of improvement of the working memory capacity, there are other scientific uses of Megame that seem interesting. This includes the self-assessment of memory capacity, the assessment of memory capacity related to different difficulties and different presentation modalities, and the use of this game to improve spelling and vocabulary.

Fig. 3.7 Memory capacity feedback. Better memory capacity is to the *right* for duration and *up* for number of elements

3.4.1 Self-Assessment

The Megame permits to estimate the number of elements in the game, by increasing the number of letters that forms a word, or by randomly presenting words of different number of letters, and in that way assessing the limit of the memory capacity with respect to the number of elements. In a similar manner, the presentation rate of the letters can be varied such that the first letters may be eliminated because it extends the time limit of the working memory and the duration of the participants working memory may be assessed. The estimation of these limits in working memory capacity is presented to the participant in the Fig. 3.7, where the goal is to approach the upper right corner (the sun, denoted Goal) as much as possible.

It is interesting to observe the difference in memory capacity improvement with and without the feedback. In addition, it is also possible to assess this with regards to the different difficulty levels that are included in the game. While it is unlikely that the memory and the difficulty are directly related, it is more probably to find results linked to the notion of flow [15], in that good performance is found when the difficulty is high enough so as to avoid boredom, but not so high it creates anxiety.

3.4.2 *Other Scientific Uses*

While the memory capacity assessment is the central goal of the Megame, other uses are also envisioned. This relates to the use of this game to improve spelling and vocabulary, as it is believed that the repeated use of the game by children will expose them to the spelling and the words in a game environment that provide additional motivating. However, the assessment of spelling and vocabulary skills is not currently targeted.

The next version of Megame under development contains different modalities in addition to letters and words, for the visible target-word version. It is the plan to assess the learning modality preferences [19] by measuring the memory capacity for different modalities. Thus, the new Megame version should provide an alternative method to establish the learning modality preference.

3.5 Conclusions

This work presents the design and implementation of Megame, a multi-platform game (including PCs and Android tablets) that can be used to train and assess memory, both by instant self-assessment and by measuring and assessing long-term effects.

Megame is based on research in memory, in particular the working memory. While it is not clear that the working memory, in terms of duration or number of elements can be improved outside the task (winning at Megame), the main improvement possibilities identified here are attention and interference. If attention is improved, or interference decreased, the activation strength of the element in memory is increased, which also increases the probability of that element entering the long-term memory.

While Megame is made principally for training and assessing the capacity of working memory, other uses of the game include fundamental research in learning modality preferences, spelling and vocabulary training, and assessment of flow.

Megame has been made using an agile and iterative approach. The game is written in Python (and pygame) a very good language for rapid prototyping that offers great productivity. It was possible to go through few design-develop-test cycles in few hours, and use the prototypes to quickly explore various gameplay. Being able to deploy on major operating systems as well as on android OS, we can reach many types of users and our game can be played in different situations (e.g. while commuting), extending the base of our potential users. We are currently working at finishing a major release that encompasses both gameplay described in this work.

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