Free Your Brain
A Working Memory Training Game

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Abstract. Working memory training systems are designed to improve the user's working memory. However, current systems are frequently considered tedious deeply affecting the user's motivation and consequently the potential for training derived improvements. "Free Your Brain" is a brain training game combining insights from cognitive neuropsychological theories and flow theories. In this work we describe the game and its design process specifically establishing the link between the supporting theoretical background research and the developed solution.

1 Introduction

Technology enhanced learning is currently being used in many different domains ranging from conflict resolution skills to math teaching [1, 2]. Since the discovery of the possible positive impact that memory training games can have on several cognitive skills (e.g. knowledge acquisition) some training systems have been developed [3]. These systems have a potentially great impact for both healthy people who simply want to improve their cognitive skills and people with specific neurological disorders (e.g. Attention Deficit Hyperactivity Disorder - ADHD). However, despite the diversity of training systems and games developed the effectiveness of such systems is still controversial [4, 5].

Cognitive training applications, and specifically working memory training systems are designed to improve the user's working memory. However, conventional systems are frequently considered tedious or repetitive which deeply affects the user's motivation to learn and consequently the potential for learning transfer [6]. According to Prins *et al.* [7] working memory training with game elements significantly improves motivation and training performance. To further explore these benefits in this work we present the brain training game "Free Your Brain" which addresses this gap in current systems by combining insights into how to keep users engaged in the learning process by using concepts of Flow theory [8, 9] in conjunction with a working memory training task design from neuroscientific studies [4, 5].

The document is structured as follows. In the next section we review existing brain training software. Then, we introduce the main theoretical background research supporting our game, followed by the description of our game and the link between background research and the developed. Finally, we draw some conclusions and present future work.

2 Existing Brain Training Software

Currently there are several commercial brain training software solutions available (e.g. Cogmed[3], Luminosity[4]). However, these solutions cannot support their impressive claims [10] sufficiently either by having controversial studies or by a complete lack of empirical studies (to our knowledge). One of the most scrutinized cases is Cogmed. In [5] Shipstead *et al.* concluded that Cogmed's claims of working memory capacity improvements are unsubstantiated. Regardless of Cogmed's criticism the authors do not exclude the possibility that effective working memory training (in capacity and related abilities) is possible. As a result of the analysis, it is suggested that future approaches should focus on training based on theories for specific working memory aspects and study their transfer effects. In a meta-analysis by Hulme and Melby-Lervåg [10] the previous criticism is reinforced and it is emphasized the need for a more theoretically motivated research that tests those theories. One aspect specifically focused the recommended utilization of multiple measures in the studies performed. Gathercole *et al.* [11] explores the value of the different studies and attempts to address Cogmed's controversy. In this work, the authors call for a balanced evaluation of all the data available relating current problems in assessing the effects of training software to the experimental designs used in several experiments. As such, the authors argue for a more careful experimental design at its different levels: multiple measures, test generalization, random participant allocation, control group.

In summary, even though there are several brain training applications available these do not support trainee motivation or lack empirical evidence [12, 5, 10]. When such brain training software or cognitive training in general is used for extended periods of time or in an even more crucial context of rehabilitation of neurological patients, motivation quickly decreases and the training outcome could be reduced [13].

3 Theoretical Background

In this section we introduce the fundamental theoretical background research that supported the design process of our brain training game. First we review

[3] `http://www.cogmed.com/`
[4] `http://www.lumosity.com/`

neurophysiological evidence to the importance of working memory training and determine what tasks are appropriate to perform it. Next we will introduce Flow Theory as a promising contribution towards addressing the boredom typically faced in current brain training games.

3.1 Neurophysiological

Trying to train working memory is very plausible for patients (e.g. stroke, ADHD, etc.) as well as for healthy adult persons. Working memory is a brain system that allows the human to manipulate and recall a limited amount of retained chunks of information for a brief period of time [14]. Numerous studies demonstrated that working memory is of central importance for acquiring knowledge (e.g. [15]) and is involved in a variety of complex cognitive tasks and abilities (e.g. [3]). Alloway and Alloway [16] showed that working memory is even a better predictor for academic success than intelligence. Thus working memory is also a strong predictor for reading and mathematical skills [17].

Literature on working memory training shows that core training of working memory is especially promising. Core training studies typically involve tasks using sequential processing and frequent memory updating components integrated with a design targeting domain-general working memory mechanisms [4]. One very common and successful approach of core training paradigms is the complex span task. Basic simple span tasks require the participant to remember and recall a number of items which have been presented without interruption. Whereas in complex span tasks participants have to execute, after each presented item, a distractor task. For instance, participants have to remember a sequence of one-digit numbers. These numbers are presented sequentially and after each number the participants have to solve an easy equation (e.g. 6+8=15, true or false?) and maintaining the presented number(s) in their temporary storage. Complex span tasks are a reliable measure of complex cognition [5].

3.2 Flow Theory

Flow or a state of flow, was introduced by Csikszentmihalyi and occurs when a person is completely absorbed by its current activity [8]. Such a state is considered optimal [9] because it is driven by a high intrinsic motivation towards the activity that leads to personal positive experiences such as immersion, enjoyment, fulfillment and skill. However, flow is not easy to achieve since it actually only corresponds to a narrow band of experiences [8]. If a given activity is very challenging but a person has low skill at performing it, instead of flow he/she is lead to a state of anxiety. Conversely, if the person faces a very easy activity and he/she has high skill at performing it, again flow is missed and a state of boredom might be reached.

Even though a flow state can have diverse beneficial psychological impacts on people (such as the mentioned positive experiences) we are especially interested on its impact on learning. Webster *et al.* [18] explored this important link and verified that indeed a flow state has a positive impact in learning. Furthermore, the authors verified this impact in a context of human-computer interaction also expanding the theory's range of applicability from psychology to human-computer interaction.

In [19] Kiili introduced an adapted version of the theory of flow for virtual environments, specifically to game based learning. According to the theory, there are several main "flow antecedents" [20] that should be considered to achieve a state of flow and consequently its learning effects:

- **Clear Goals** - clear goals facilitate the learner's focus on the activity which is related to a higher probability of experiencing flow;
- **Feedback** - helps the learner monitor his/her performance and progress and also avoid distractions, both related to a higher probability of experiencing flow;
- **Playability** - overly complex activities or interaction with the learning system are related with a lower probability of experiencing flow;
- **Sense of Control** - the learner's perception that he/she can develop his/her skills to reduce errors in challenges should be supported. If such a balance between the challenges and skills is offered there is a higher probability of experiencing flow.

Even though "Challenges" and "Skills" were not specifically described they are both fundamental antecedents[5]. These antecedents are actually the key elements of the theory and are better characterized as a comparative dichotomy (e.g. Playability and Sense of Control antecedents). Even though Flow Theory provides several well defined antecedents each individual's experience of flow is unique as it also depends on personal characteristics such as emotions, values and previous experiences [20].

4 Free Your Brain Serious Game

In this section we will detail our approach to design a solution addressing the problems faced by current working memory training software and also how this solution was actually implemented to be tested in a real context.

4.1 Approach

In the development of "Free Your Brain" we specifically intended to address the lack of motivation and the lack of empirical evidence of effectiveness for current working memory training software solutions. Based on our neuropsychological background research by using a complex span task as our core central activity we have a better chance of success in achieving working memory improvements. Therefore, we selected such a task as a basic design choice. To address the lack of motivation we introduced several game elements designed around the central

[5] Such that they are the frequently used as the basic determinants of Flow Theory prediction.

activity expecting to improve motivation and increase the learning outcome. Flow Theory provided us with a set of design guidelines that were used to increase the probability of players achieving a state of flow.

4.2 Complex Span Task Activity

The game was designed to guide the player through cycles of a complex span task activity. The activity is composed by a sequence of phases that are typically[6] presented in the following order:

1. **digit presentation (DP)** the game displays a one-digit number (*key-digit*) that the player must memorize until the unlocking phase;
2. **decision task (T)** the game presents a simple arithmetic decision task (e.g. $5 + 6 = 11$) that the player must classify as either true or false;
3. **unlocking (U)** the player is asked to recall the key-digit initially presented;

This complex span task activity can be parameterized in terms of difficulty by varying the number of $DP \rightarrow T$ phase pairs before reaching the U phase. The digits to recall in this phase are all those that were previously presented in each DP phase. The number of digits to remember is therefore directly proportional to the number of $DP \rightarrow T$ pair sequences that precede it.

4.3 Game Description

The game is presented to the player as a personal quest of *freeing one's own brain*. Upon entering the game, a player can see a high score table displaying his/her best game sessions in this quest. After this, the player can then start a new session. If it is a first time player then he/she starts at level 0 otherwise at a slightly lower level than in his/her previous session.

Each level is composed by two sequential and equally difficult complex span task activities. If a player is able to successfully complete two equally difficult tasks then he/she advances to the next level. For each level that the player advances the complex span task to solve is increased in difficulty by adding one more $DP \rightarrow T$ pair relatively to the previous level. For example, in level 1 the player is presented with the following complex span tasks composed by the following phases: $DP \rightarrow T \rightarrow U$. However, in level 2 he/she faces tasks with the following phases: $DP \rightarrow T \rightarrow DP \rightarrow T \rightarrow U$. Generically, for level n a player faces n phase pairs $DP \rightarrow T$ before entering phase U.

As in any game, the player can make mistakes and in the specific case of "Free Your Brain" these occur either at the T phase or at the U phase. An error in any of these phases results in the player restarting the current complex span task from the beginning. However, if the player makes two mistakes, in the same level, it levels down and starts a complex span task with a lower difficulty. This procedure allows the players to train at the optimal level of their capabilities. Furthermore, the adaptive difficulty of the game should ensure maximum performance of the players [21]. The flowchart presented in figure 1 represents the possible paths in player progression according to the different phases of levels 1 and 2.

[6] Assuming an error free progression.

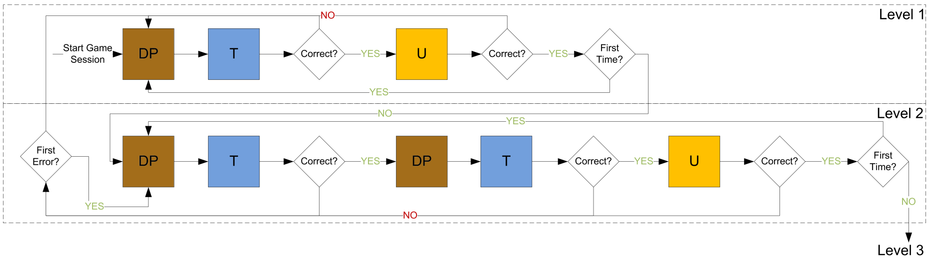

Fig. 1. Components flowchart for level 1 and 2. DP - Digit Presentation; T - Decision Task; U - Unlocking.

During the game the player receives visual feedback of correct (growing neuron animation) or wrong (shrinking neuron animation) according to the result of the *T* phase. Visual feedback of correct (attempting to or unlocking current level's brain area animation) or wrong (locking current level's brain area animation) is also displayed according to the result of the *U* phase. When a player either levels up or down this information is emphatically displayed. Finally, the player always has the current score bar visible, see figure 2.

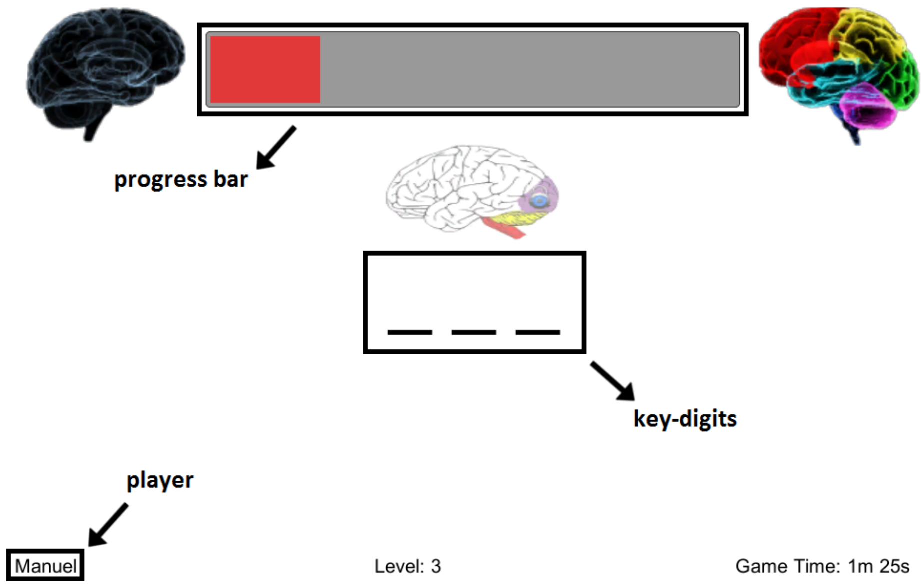

Fig. 2. Game interface

4.4 Elements of Flow

In this section we will explore the link between the diverse game elements and Flow Theory.

Clear Goals A higher probability of experiencing flow exists when a game has clear goals. In line with this "Free Your Brain" has a very simple goal: unlock as many parts of your brain as possible by reaching higher levels in each game session.

Feedback Several game elements help the player monitor his/her performance and progress which also increases the probability of experiencing flow. Preceding any game session the player can assess his/her overall progress across all game sessions by checking his/her personalized highscore board. After starting a game session the player then has several feedback systems. First, and always present, is the score bar that enables the player to check his/her current session score instantly and compare it with previous ones. Second, there are several visual elements to depict different game events or phases. For the *decision task (T)* phase if a player gives the correct answer then a growing neuron animation is played to convey that information, otherwise a shrinking neuron animation is played to represent a wrong answer.

In the *unlocking (U)* phase the player also receives visual feedback. Initially he/she is presented with a brain image with a specific part of the brain locked. Then according to the digits provided, if correct and it is the first *unlocking (U)* the player faces in that level then a brain struggling to unlock animation is played. If also correct, but it is the second time, then an unlocking animation specific for that level (represented by a specific part of the brain) is played. If the digits provided are incorrect then an animation emphasizing the locking of that part of the brain is played.

Finally, in any level up or down event the player is presented by a visual notification informing his/her about that change in game difficulty.

Playability Regarding playability several game characteristics contribute to a higher probability of achieving flow. First, the actual tasks included in the activity are very simple: observe a digit, reply correct or wrong, input one or more digits. Additionally, the provided modes of interaction are also very simple by being straightforward to the action the player has to make: click a button displaying correct, a button displaying wrong or simply press key digits in the keyboard.

Another important design decision that contributes to achieving flow is the avoidance of working memory cognitive overload by balancing the amount of visual elements [19]. To this end we excluded from the game all visual elements that did not have a specific function and therefore added value to the learning goals. This game characteristic helps the player avoid distractions and keep focused on the game's central activity.

In the creation of the images and animations for the *unlocking (U)* phase special attention was given to the brain diagrams and their locked or unlocked areas. Each level had a specific region of the brain locked which was unlocked by successfully completing that level. An area unlocked in a given level always appears unlocked in the higher levels to give the player a sense of progression in his/her goal to "unlock the brain".

Sense of Control The flow antecedent sense of control specifically focus the attainment of the player's specific correct balance between the difficulty of the challenges presented and the player's skills. As recommended by Flow Theory we introduced an adaptation mechanism that adapts the level of difficulty and consequently the challenges presented to the player's proficiency in the activity.

The player's good performance is rewarded by letting the player progress in the game. However, and in order to support the sense of control a player can only level up and face a harder complex span task by completing the same difficulty task twice. If a player makes one mistake it is not immediately leveled down, but given a chance to correct his/her mistake. However, if a second mistake is made, the player levels down so that the complex span task challenge presented is more adequate to the player's current skills and avoids an anxiety state. Furthermore, given our task design the changes in difficulty are progressive and avoid irregular spikes by occurring at a set pace of one $DP \rightarrow T$ phase pair per level change.

To ensure that players train/play close the maximum of their capabilities and avoid a boredom state we also introduced a starting level dependent on the previous gaming session's final level. A new session's initial level corresponds to the previous session final level decreased by a pre-determined amount of difficulty (corresponds to one or more levels down).

4.5 Game Implementation

The "Free Your Brain" game was developed as a web application so that the players are able to perform the training online from their own computers. Players log in with personal credentials and the performance of each training session is saved in the webserver.

The technologies used to implement the game were Unity 3D (using C#), MySQL and PHP. We opted for Unity 3D because it is a powerful framework that enables us to build a web-based game efficiently, enables an easy deployment of the game and easy access to the players. MySQL was used to store collected user data persistently for posterior evaluation and to support the level related personalization mechanism. Finally, PHP was used for the creation of an interoperability layer between Unity 3D and MySQL on the webserver hosting the game.

The implementation of the game required the conception of technical solutions to diverse challenges. Given the requisite of high parameterization capability we developed a preferences loading system so that someone deploying the game could easily switch between different versions. A given game version can be easily parameterized or fine tuned by altering different game aspects such as the available decision tasks, the scoring system and game timings.

5 Conclusion and Future Work

In this work we present a working memory training game designed to include insights from both neuroscientific studies and Flow Theory adapted to virtual environments for game based learning. The neuroscientific studies provided the fundamental activity around which the game was designed and the guidelines of Flow Theory were carefully intertwined in the game mechanisms to try to support player motivation. Additionally, given the methodology and choices made in its implementation the game is easily parameterizable to create different versions that can be easily distributed to the player's personal computers.

As future work we intend to empirically study our solution. To this end we are currently undergoing a study to examine if the developed working memory training game leads to an increased training outcome in comparison with a version without game elements. The two versions are exactly the same except for the game elements. In this study we use multiple measures to assess participants' cognitive abilities changes. If transfer effects are found we will conduct a magnetic resonance imaging (MRI) study to examine morphological and functional changes induced by our working memory training game.

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