The Clinical Potential of a Cognitive Training Program Embedded in an Adaptive Video Game

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***Abstract*—Cognitive training programs commonly involve single game features, but they are rarely embedded in a complete, adaptive video game where the player can experience *game-flow*. The aim of this paper is to present a video game designed to train users' cognition across five key domains and to describe its potential. The training program is calibrated based on the individual scores obtained in a self-administered, online assessment targeting attention, working memory, episodic memory, executive function, and processing speed, which is automatically linked to the video game software, adapting itself to the player's progress. Structural features in the game contribute to creating an engaging experience for the users. Successful examples of implementation of the program have been tested in diverse settings, including educational programs and clinical trials. Improvements in cognitive function and transfer effects in academic and everyday life skills and behavior have been demonstrated and show promise for further analyses. The adaptive mechanisms and the game-like structure of the presented training program make it a potentially valuable starting point for further research on innovative cognitive programs.**

Keywords-Cognitive assessment & training; gamification; adaptive video games; performance improvements.

I. INTRODUCTION

Computer-based solutions for cognitive training are becoming progressively more popular in the commercial, clinical, educational, and business sectors. Most of these solutions have introduced elements of *gamification* [1], including feedback, an achievement level structure, competitions, and time pressure. However, only a few of these show a true involvement of the player, typically observed in the most sophisticated of video games, which can produce a *game-flow* experience. Flow may be defined as the complete absorption in an activity in which a person is involved [2]. In the case of gaming, the flow primarily depends on how much the game itself is adaptive, i.e., how much it can modify itself according to the user's progress to be sufficiently challenging. Other factors producing the flow experience may be a representation of the self inside within the game, a 3D environment, a narrative context, or a music background [3].

Traditional brain-training programs may be considered as a separate category compared to the video games, as they do not completely incorporate such game features, stopping at a puzzle level [4]. Most traditional cognitive games only introduce single game features, such as progress bars, level structure, and feedback, without producing an actual video game, even if some exceptions have been identified [5].

However, the cognitive programs following this type of approach do not embed an assessment tool to monitor the progress in cognition and to set in the game a level of play adapting to the user's cognitive level.

The aim of this paper is to present a novel approach which attempts to overcome these limitations by proposing an online, self-administered software tool, integrating both an assessment and a training program, where the training is embedded in an engaging video game, MyCognition AquaSnap.

In Section 2, the MyCognition software, integrating a cognitive assessment and a training video game is introduced and game elements are described. The structure of the training game will then be described more in more detail in Section 3. Some examples of successful adoption of the MyCognition programs are presented in Section 4, underlining the training conditions necessary to gain performance improvements. In Section 5 some considerations about future perspectives will be appraised and future directions will be outlined in Section 6.

II. THE MYCOGNITION PROGRAM

AquaSnap is a scientifically designed, cognitive training video game developed to improve cognitive function, targeting five key cognitive domains — attention, working memory, episodic memory, executive function, and processing speed [10].

To produce personalized training for every user, the amount of training for each cognitive domain is calibrated on the individual scores obtained in a cognitive assessment integrated into the system, the MyCognitive Quotient (MyCQ) assessment. MyCQ comprises a digital version of the most validated psychometric tests widely used over almost 200 years of neuropsychological research in their original, traditional, paper-and-pencil versions. In contrast, MyCQ is an online, self-administered assessment, whose final scores for each cognitive domain are automatically generated by the software system and feed the game engine. In this system, the lower a player's score in a particular cognitive domain, the more intense the training will be for that domain.

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The game has an aquatic theme in which players must venture into the ocean to undertake various activities. The activities include exploring rich underwater worlds populated with a range of fish and sea creatures, seeking out and photographing different types of fish, each with their own characteristics. The photos are placed for sale on the open market, to build wealth and reputation for the player. Finances must be mastered, as currency is spent to push further into the ocean to see the rarest and most elusive of fish.

The game is built from the player's self-perspective, which is represented in the ship moving across the ocean chart and in the camera's lens in the underwater environment. The ocean chart itself embeds a narrative aspect in the game, as it tracks the players' progress history and can be explored backward and forward. The evocative names of each oceanic area contribute to make the environment the scenario of a narration.

Moving from the 2D environment of the map to the underwater zone, the player can experience a 3D environment with the illusion of moving through the water and encountering different objects and animals as a part of each training task. The music in the background also contributes to creating a flow experience, facilitating the player's concentration during the training and ultimately advancing to produce a longer-term effect on behavior, as suggested in studies involving children with behavioral difficulties [7].

III. THE STRUCTURE OF AQUASNAP

The training works by encouraging the player to undertake repetitive, and increasingly more challenging, tasks that are embedded in the video game. The tasks are designed to train a specific cognitive domain.

Each cognitive domain is mainly trained by a specific loop, with some domains trained using several tasks. The game develops on different structural levels. At the basic structural level, there are the loops which correspond to the five first tasks in Table 1. The loops are organized in dives, so that in each different dive the user can experience a set of loops.

The ocean map represents a meta-level of cognition. At the map level, users must organize their dive to both achieve the proposed mission and to discover new areas.

The progress of the players on the map, and consequently the growth of difficulty in the training game, depend on the coins the players can collect during their dives. In this way, the game adapts its difficulty to the level of improvement reached by the player.

The intensity of the training depends on the individual MyCQ scores, too, as mentioned above, as the number of loops for each type of task that the user experiences depends on the score obtained in each cognitive domain. In this way, more impaired domains will receive more intensive training.

TABLE I. INDIVIDUAL TASKS IN AQUASNAP AND TRAINED DOMAINS

Task	Task Description		
	Name	***Activity***	***Cognitive Domain***
1	Memory Shot	Remember the position of the glowing fish in the loop.	Working Memory
2	Quick Shot	Snap the fish as soon as you see it.	Processing Speed & Attention
3	Careful Quick Shot	Snap the fish as soon as you see it, but be careful not to snap the shocking fish.	Attention & Executive Function
4	Group Shot	Snap the group of fish when all together.	Attention & Processing Speed
5	Fish Tracker	Remember which fish are glowing after they change position.	Working Memory
6	Oceanic Survey	Remember which fish you have seen at the end of the dive.	Episodic Memory
7	Missions & Map Exploration	Achieve the goals proposed by the daily missions and try to discover new areas on the ocean map.	Executive Function

In the following section, further details about the amount of time the users play the training game and in-game adaptive mechanisms will be introduced, as these relate to real-world implementations of the program.

IV. MYCOGNITION PROGRAM IMPLEMENTATION STUDIES

Considerable evidence has been produced in randomized controlled trials (RCT) in clinical and school settings and in individual and group case-studies in school and home settings, as described in the following paragraphs. These have shown the effectiveness of the described training video game in improving players' cognition and related performance for different categories of users. MyCognition generally recommends following the training program by playing the cognitive game at least 90 minutes per week, at least three times each week for eight/twelve weeks, and taking the MyCQ assessment at the baseline, in the middle, and after the conclusion of the program. The game itself keeps track of the diving time and displays it to the player. Also, the game proposes among the daily missions the task of playing at least 15 minutes in order to get 3 coins. As the coins are an essential tool to progress in exploring the oceanic map, players not complying with the recommended time adaptively have a slowed progress through training levels, which corresponds to their slowed cognitive improvement.

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Users following the recommended program are usually able to get at least a 10 points increase in their MyCQ score on a scale going from 1 to 100, corresponding to a 20% increase for the average population, having a baseline score of 50 points.

The first clinical evidence came from two studies involving a psychiatric population affected by schizophrenia, schizoaffective disorder, obsessive-compulsive disorder, and major depressive disorder. Significant improvements in episodic memory were shown in the group of patients playing the cognitive game in addition to the usual treatment [15].

Outcomes are currently being measured across all the key cognitive domains in a Parkinson's disease population with mild cognitive impairment [18].

Several other clinical trials are ongoing, investigating the usefulness and usability of the cognitive video games in populations with neurodegenerative and psychiatric disorders and in other conditions, including cancer.

Evidence of the effectiveness of the training program and the attractiveness of the video game have been studied also in various education scenarios, involving mainstream and special educational needs students. In addition to improvement in cognition, students of different ages also showed advances in their learning skills, in academic achievements, and in class behavior [11][12][17].

Current studies are still investigating the usability of the programs in other contexts, such as social and health services and corporate wellbeing, showing preliminary promising outcomes [16].

V. FUTURE PERSPECTIVES

Once the potential and the effectiveness of the training program presented has been shown in different settings, a further step in the development work would be to export the basic structure of the game and its different cognitive tasks t other analogous video games with different environments which can embed the training program itself.

Also, further research can be done in order to develop more sophisticated features to enhance players' engagement and the game's user-adaption, together with more sensitive assessment tasks and training loops.

Evaluations of similar and comparable studies can also be deepened, as well as analogous counterparts in the fields of serious games and exergames.

VI. CONCLUSION

Even if the work presented has limitations due to its "in progress" state, some innovative points have been identified and early evidence of the potential of the program has been shown. Future research can lead to the development of more sophisticated game features that are able to produce a more totally engaging game-flow experience in different categories of players, from the youngest children to the elderly population.

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