NEEURO MEMORIE:
IMPROVING COGNITIVE WELL-BEING WITH GAMIFICATION AND EEG

1. RESEARCH ON COGNITIVE TRAINING

Our cognitive abilities, such as reasoning skills, working memory and multitasking performance may diminish significantly throughout the span of our adult life. In fact, studies have revealed a linear relationship between the declines in our mental faculties and aging, as early as in our twenties [1-2].

Nevertheless, to slow down or even prevent the onset of cognitive aging is possible. Just as we are able to build up our muscles in the gym, our brains can, too, be exercised.

Numerous studies and clinical trials have been conducted by scientists worldwide in an effort to try to understand the causes of cognitive decline and the corresponding preventive measures to combat them. These include reports that have shown cognitive training played a positive role in improving our fluid and crystalized intelligences [3-7] while also being sustainable [8-10] and transferable to our daily functions [11-26].

Perhaps most prominently, a large scale meta-study based on more than 250 high quality publications conducted by the National Institute

of Health (NIH) confirmed cognitive training as a highly effective protective factor in combating cognitive decline [29].

A person's cognitive status can be assessed by standard tests such as RBANS [27]. In a recent NPR article, a former NRP correspondent talked about her experience in taking a 20-day brain training program, which to her surprise, yielded a gain of 75% in the assessment [28].

Whereas traditional measurements on the impact of cognitive training were based solely on assessments, today's fMRI and neuroimaging techniques have allowed researchers to observe the direct impacts the training has had on specific parts of the brain. These advancements have also given rise to the field neuroplasticity, giving credence to the notion that our lives can be improved through the training and refinement of our brains [30-32].

In fact, cognitive training has demonstrated benefits across all age groups, from children as young as to the elderly [33-44]. At the same time, it has also been shown to be an effective alternative therapy for patients suffering mental illness or other diseases [45-64].

One particular study investigated the effects cognitive training had on a person's life across three distinct age groups (8-10, 18-26, 62-76 years of age) in a pre and post-training design. The study found that the transferable effects of training were observed in all age groups, with especially significant results amongst the elderly participants [65].

Overall, the overwhelming evidence found for the effectiveness of cognitive training provides a strong scientific basis for brain exercise, especially for the elderly.

2. GAMES FOR BRAIN

Engaging in meaningful activities is crucial for people to improve quality of life. For those who have limited activity opportunities and are under-stimulated, computer games offer a means for them to stay active mentally and engage positive stimulations. Research has shown that computer based brain training improves memory and performance of everyday tasks in older elderly [66-67].

Mobile applications and computer games become increasingly inevitable in today's world. Driven by US National Science Foundation, neuroscientists and entertainment experts have initiated the collaboration being [68] on future development of computer games for further our understanding of brain functions and to provide new tools to foster brain plasticity, boost attention and well-being. The gaming industry is on its way to bring potentially therapeutic games to market [69].

3. EEG-BASED COGNITIVE TRAINING

In a 2013 study published in Nature investigating the impact of specially tailored computer games on multitasking ability, the use of electroencephalogram (EEG) by its researchers in brainwave capture proved an effective method in determining the cognitive abilities of its participants [1].

In fact, numerous studies have reported associations between EEG biomarkers and cognitive functioning. For instance there is a high correlation between the level of theta activity (4–7 Hz) within the brain and one's working memory [70-71] while sensorimotor rhythm (SMR) activity (12–15 Hz) is generally associated with one's attention level [72-73]. Engaging individuals in tasks that enhance

such brain activities (termed 'neurofeedback' in neuroscience) can possibly help to dramatically improve their cognitive performance through a closed-loop fashion.

With regards to the possibility of diminishing cognitive gains during training due to cognitive overload, the use of an adaptive real-time monitoring system using EEG biomarkers which can effectively control for mental fatigue would be able to deliver a significant improvement to the results of training interventions [74].

As demonstrated in [75], subjects who played the game with an inbuilt EEG-based neurofeedback functionality showed significant gains in attention/cognitive skills as compared to those who did not/the control group. In another study conducted by [76], researchers concluded that normal healthy individuals possess the ability to intensify a specific component of their brain activity, which may facilitate semantic processing in working-memory-dependent tasks and to a lesser extent, those requiring focused attention. In a further study [77] focused on spatial tasks, subjects who were able to increase their upper alpha power (responders) performed better on mental rotations after EEG-based training.

In conclusion, the use of EEG in facilitating closed-loop cognitive training provides such exercises with real-time measurements of a participant's mental state, ensuring an adaptive training program working to effectively maximize its benefits.

4. Neeuro Memorie

Neeuro Memorie mobile application equipped with Neeuro EEG headband, SenzeBand offers a unique solution for brain training, which can be done in a fun manner, anytime and anywhere.

Pyramid Solitaire

Unlike the classic pyramid solitaire where unused cards are promptly disposed of, Memorie's version allows the player to store these temporarily unused cards separately for future use. These stored cards are stored faced down, posing a challenge to the player to recall the cards' values from memory, and any wrong guesses, results in a score penalty. These simple exercises have indeed been demonstrated to improve cognitive functions [78], and research has shown that such procedural long-term memories remain robust even in cases of Alzheimer's disease [79].

To effectively tackle the onset of memory-loss, enhancing short-term memory retention remains key. With the introduction of card storage, players are now required to access their short-term memories, remembering the exact placement and value of the stored cards and retrieving this information where necessary. In addition to improving the player's working memory, the need to constantly task-switch – focusing his/her attention not only on the current arrangement of cards on the board but also the cards' corresponding relevance to those faced down - has been shown to promote cognitive flexibility [80].

Improvements to players' strategic decision making is another key aspect of our game design. With new research showing evidence of a four-item working memory limit [81], it would be unwise for players to store too many cards at once. Instead, they are encouraged to think strategically about card storage, lest one runs into the risk of forgetting values of the cards stored and incurring a score penalty.

With recent studies linking neuroplasticity with intellectual stimulation [82] and confirming the transfer effects of video games aimed at improving cognitive functions [83], this modified version of the classic game of solitaire is likewise able to provide the players with an avenue for brain stimulation and ultimately serve as a viable solution to preventing the onset of memory loss.

SUSHI RECALL

Sushi Recall is a fun version of an N-back task [84], an assessment in cognitive neuroscience to measure a part of working memory. During the game, the player is presented with a sequence of sushi plates supplied from a conveyor belt. The player needs to indicate the type that matches the one from ***n*** plates earlier in the sequence. The step factor ***n*** (range from 1 to 4) and types of sushi (range from 2 to 5) are increased to make the task more difficult when the player is upgraded to the next level.

Human brains are only capable of storing a limited amount of information in their short-term memories. In an N-back task, the working memory buffer needs to be updated continuously to keep track of what the current stimulus must be compared to. To accomplish this task, the subject needs to both maintain and manipulate information in working memory.

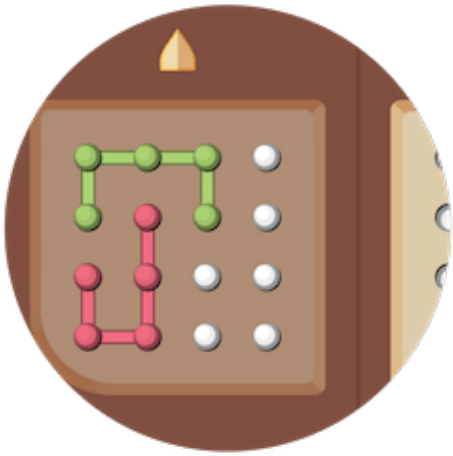
Although it remains controversial if *n*-back training produces real world improvements to working memory [85], several studies have shown that a proper training will benefit the cognitive processes required for memory. In [86], cortical thickness and cortical surface area (the brain regions support working memory) were measured before and after completing a challenging adaptive cognitive training program based on the n-back task, a positive effect was observed. Interestingly, it was found that the training was more beneficial for low intelligence individuals. Another study suggests that adaptive n-back training does not improve fluid intelligence but may enhance visuospatial processing [87].

DOT CONNECT

Dot Connect is a game which aims to improve visual-spatial abilities. The player is given an initial picture of variable shapes represented by a series of connected dots and then asked to reproduce it in either of the following cases: rotated or flipped (includes mirrored).

While visual-spatial ability (one's ability to manipulate 2D/3D figures) is seldom discussed

relative to short-term memory loss in cases of cognitive decline, it remains an important subset of our general intelligence [88]. Visual-spatial ability is in fact fundamental to daily functioning, with elderly persons experiencing decline in this department reporting difficulties in driving, navigating new routes and forgetting the placement of everyday items [89].



Our game seeks to alleviate the onset of such symptoms by taking advantage of the malleability of spatial skills [90], improving players' abilities through a series of increasingly more difficult puzzles. A color guide is improvised in the earlier stages to familiarize elderly players with the rules of the game, after which later stages provide a greater challenge with no color-coding.

The improvisation of multiple shapes on the same 2D plane seeks to target multiple aspects of a players' spatial visualization ability. The re-orientation of a singular object requires the player to utilize his/her egocentric spatial ability [91] by taking on a different perspective in space to the one initially shown. Subsequently, the player would find it much easier to reference the placements of the other two objects through an analysis of the picture as a whole, developing his/her allocentric spatial ability in the process.

At the same time, EEG sensors are attached to our players to evaluate the players' level of visual spatial attention as well as the focus of their spatial attention [92], providing accurate measurements in tracking their overall progress.

MIND COPTER

In the Mind Copter game, the helicopter is controlled by the brainwave captured by the frontal EEG sensors. The player needs to focus in order to lift the helicopter up and fly to perform the rescue mission. At higher game levels, the helicopter becomes heavier and more obstacles are introduced to challenge the players in controlling his/her brain state.

Studies have shown the association between EEG biomarker and attention level [72, 73]. The use of EEG in facilitating attention training provides exercise with real-time measurements of a participant's attention level, ensuring an adaptive training program working to effectively maximize its benefits.

Each of Memorie's games is designed to train one or two specified core cognitive capacities, including Attention, Memory, Spatial, Multi-tasking and Decision Making. These games can be used towards a training program which could be personalized based on the cognitive profile

and personal needs in a particular cognitive area.

Moreover, the EEG headgear, SenzeBand together with the Neeuro Memorie mobile application provides real-time monitoring of a player's cognitive state. Analyzing EEG-based brainwave not only gives an extra dimension to game scoring, but also tailors a personalized guidance to engage players enhancing their brain activities, which will improve their cognitive performance.

5. Conclusion

We are in a world of rapid information growth and unprecedented longer lives. Both factors place great challenge for us to maintain cognitive fitness through life. To enhance our cognitive well-being and prevent cognitive decline, it's important to engage ample mental exercises in addition to a healthy lifestyle.

The effectiveness of brain training has been advocated by decades of scientific research. In the meantime, mobile applications and computer games become increasingly inevitable in today's world. Mobile games paired with lightweight EEG sensors make it possible to facilitate closed-loop cognitive training in daily life, offering adaptive, handy and powerful training programs for effective brain exercise for everyone, anytime and anywhere.

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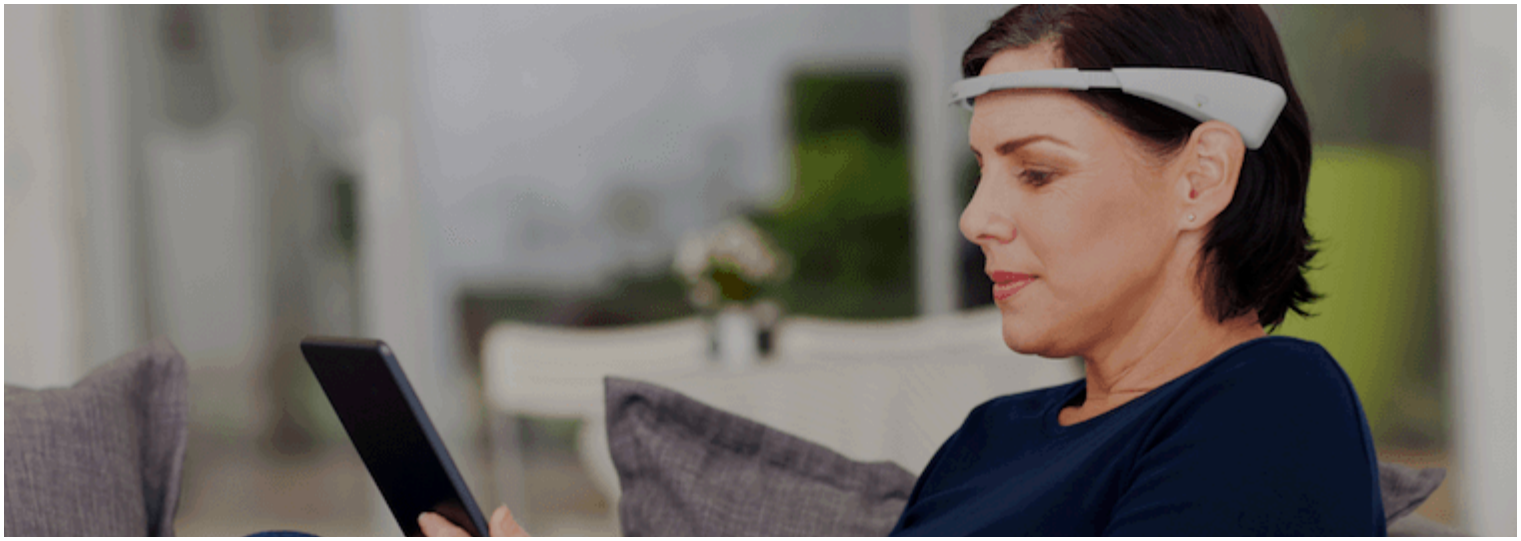

ABOUT NEEURO

Neeuro's mission is to develop innovative products that empower people to live happier, healthier and more productively through the use of neurotechnology and gamification.

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