Enhancing ‘Find the Treasure’ Game Experience: The Role of Haptic Feedback and Visual Cues

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***Abstract*—The long-term goal of this research is to be used as a multimodal tool to aid in memory training for persons suffering from cognitive diseases, such as dementia and Alzheimer’s. Together, dementia and Alzheimer’s effect 697 per every 10,000 persons, which continues to increase every year. It has been shown that multidisciplinary rehabilitation programs significantly improve the quality of life for persons living with cognitive impairments or diseases. It has also been shown that electrical stimulation can enhance cognitive tasks. To combine these ideas, we developed a game that uses haptic feedback and visual ques. We found that, even on a healthy population, the time and moves that it took to find the treasure decreased with the combination of haptic feedback and visual ques. Specifically, we found a significant decrease in the number of moves needed to find the treasure (p = 0.001) and overall a more enjoyable gaming experience. These results show that the combination of haptic feedback from electrical stimulation and multimodal game play increase cognitive ability and increase gaming experience. Other than the field of cognitive disorders and gaming, these results could also be used for visually impaired by providing accessible systems, such as GPS watches.**

***Index Terms*—Functional Electrical Stimulation, Game Play**

I. Introduction

The number of people living with dementia and Alzheimer’s approximately doubles every 5 years [1]. Currently, gamification is widely used in rehabilitation for neurodegenerative disorders [2]. While this is not a new concept, the current standard relies on the use of deep learning models and VR. Similarly, electrical stimulation is widely used for many medical conditions, such as reanimation after spinal cord injury [3]. While these two clinical applications seem very different, we found that they can have common ground in their use for several different cognitive applications.

Recent work using gamification in healthcare focuses on the enjoyment the patients get from it [4]. Although this is very important, increasing cognitive abilities and therapeutic outcomes leaves a more lasting impact. On that note, work on multimodal therapies for cognitive disorders show great promise, including the ability to improve cognition and quality of life, while also decreasing depression [5]. By expanding upon the types of multimodal therapies available to patients, we hope to expand the patient population and improve the outcomes even more.

Electrocutaneous stimulation, which stimulates nerves through contact with the skin, is one of the most feasible techniques for generating nerve activity because it is non-invasive and can produce varying levels of sensation that can be reliably controlled [6]. Although the threshold for the stimulation variables for each persons’ ability to perceive sensation varies, some generalized ranges can be found, which removes the needed customization for the system and could make them commercially available.

In this paper, we tested different game conditions: no visual + no haptic, visual only, haptic only, visual + haptic, to understand the impact of haptic feedback and visual ques on gaming abilities and experience. This simple game works as a starting point for many more complex applications, such as therapeutic tools and assistive technologies and can impact many different patient populations. We found the combination of visual and haptic to be the most enjoyable and most effective for our study population. The number of moves needed to find the treasure decreased significantly with this pairing (p = 0.001, n = 60), compared to the other 3 conditions.

II. Methods

A. Participants

Five human subjects participated in this study, with 100% being female and ranging in age from 22-28. All participants were healthy, intact individuals with no neurological impairments.

B. Stimulation Hardware

To deliver the haptic feedback during the game, a 1 channel, high voltage stim box was used. This consisted of an Arduino Uno with a top shield. The electrodes used were medi trace, 3.6cm diameter electrodes. The electrodes were placed on the back of the hand and wrist (as shown in figure 1).

C. Stimulation Parameters

During the game, the amplitude of the stimulation increased as you got closer to the treasure. In order to cause sensation without eliciting movement, we had to use relatively small stimulation values, while still being able to keep a range where there was a noticeable difference in sensation. We decided on ramping between 2mA and 6mA, while keeping

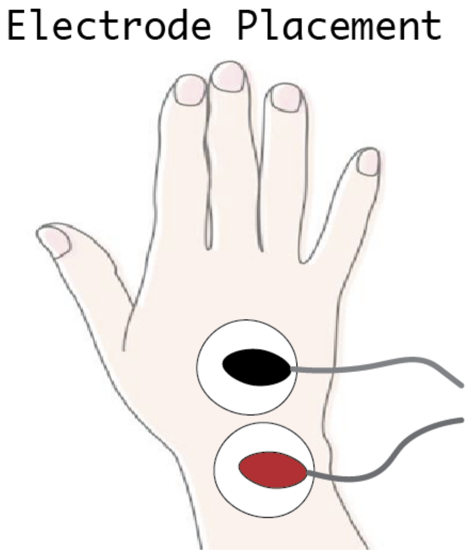

Fig. 1. We used two electrodes - one placed on middle of the hand and another on the wrist crease. While this placement worked for stimulation without evoking movement for most, one participant had to shift the electrodes more onto the wrist to prevent locking of the middle finger.

the pulse width and frequency consistent at 200ms and 30Hz, respectively.

D. Game Mechanics

Overall, the game consisted of a red block portraying the player, a black screen for the world they explore, and a yellow block for the treasure. The yellow block is only seen once the player reached the location of the treasure (figure 2,2). The condition for reaching the treasure was that the player block touched any side of the treasure (top, either side, or bottom). This was done to make the game more enjoyable to play. When you had to hit a certain side of the treasure, it was tricky to follow the visual ques or the sensation because it would show zero moves or be at max sensation already.

The haptic feedback would begin for the player when they were within 10 moves of the treasure. This meant at the beginning of the game, the player would most likely have to make moves without any sensation (based on the random location of the treasure).

1) With Visual Feedback: For the conditions with visual feedback (both with and without stimulation), the number of moves until the player reached the treasure was shown at the top (figure 2, 1 and 2). Since the player could only move up, down, left and right, the Manhattan distance was used to calculate the distance from the treasure. This was then broken down into the number of moves by finding the shortest vertical and horizontal path.

2) Without Visual Feedback: The only change made for the no visual conditions (both with and without sensation), was removing the number of moves to treasure ques (figure 2, 3). With the no haptic feedback condition, there was no way for the play to know hoe far they were from the treasure. They had to just move until they randomly hit the treasure. The rest of the game mechanics stayed the same, including the distance calculation, which was only used with the haptic feedback condition.

E. Algorithms

The game was written using MATLAB. The main algorithms used involve calculating the distance from the treasure and delivering the haptic feedback based on the distance.

1) Distance: As stated above, the Manhattan distance was used for the distance from the treasure. This is calculated using the equation shown below, where x1, y1 represent the player location and x2, y2 the treasure location. This is the ideal

$$Distance = |x1 - x2| + |y1 - y2|$$

equation given the constraints of the players movement. The distance is calculated as the sum of the absolute differences of their Cartesian coordinates. This algorithm is also less computationally expensive than others, allowing for the change in sensation based on distance to be more smooth and real-time.

2) Haptic Feedback: The stimulation amplitude is adjusted based on the distance between the player and the treasure. This adjustment is done to create a "ramping" effect, where the amplitude increases as the player gets closer to the treasure. The goal is to provide feedback to the player through electrical stimulation that becomes more intense as they approach the target. This function works by having stimulation parameters of the max distance and the max amplitude. For this game, the max distance was 10 moves away from the treasure and the max amplitude was 6mA. The amplitude is continuously calculated using the equation shown below. This formula ensures that as the distance decreases (player gets closer to the treasure), the amplitude increases. The amplitude is scaled proportionally to the remaining distance.

To ensure that the amplitude is never negative or below the minimum, the max between the minimum and calculated amplitude is found before passing it to the stimulation command (max(2, amplitude)).

Finally, the max between the two values is passed to the stimulation control function. This happens in a continual loop until the treasure is found. If the player happens to go further from the treasure after being close, the stimulation values decreases again.

$$Amplitude = maxAmplitude * (1 - \frac{distance}{maxDistance})$$

F. Experimental Conditions

For this study, we looked at four conditions: no visual and no haptic, no haptic with visual, no visual with haptic, and visual with haptic. We used the no visual and no haptic as our control, or baseline, condition. We wanted to look at the impact of visual ques and haptic feedback to find the optimal combination of both. For every condition, we ran 3 trials and one learning trial.

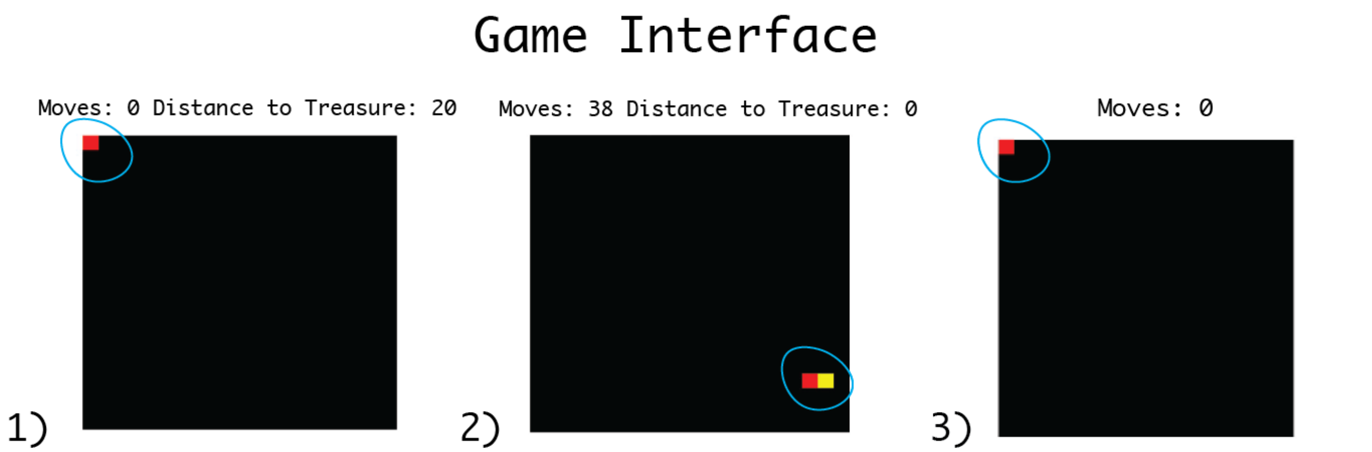

Fig. 2. The interface of the game consists of a red square for the player, which always spawns in the upper left corner. The black background is the environment they can explore. The yellow square is the treasure, which appears when the user "finds" it. 1) This shows the beginning conditions of the game, with the visual feedback of the number of moves at the top. There is also a move counter, which lets the player know how many moves they have made. As you can see, the treasure is invisible at this point. 2) The winning condition. This shows how the treasure appears when the user's red square touches it. They could touch any side of the treasure square and it would appear. 3) No visual Ques. This shows the removal of the visual ques (moves until treasure). The count of the number of moves remains.

G. Performance Metric

We measured the time it took for the user to find the treasure and how many moves they took. We used both time and moves to have a more robust picture of the impact of the conditions. The time variation could be due to cognitive processing time, while the moves show a more realistic picture of the impact of each condition.

H. Statistical analysis

We first ran an Anderson-Darling test to check for normalcy, and found the data to be normally distributed, for both the time and moves. We then ran an ANOVA to test for significant differences for the time ($n = 60$) and the moves ($n = 60$). We also ran multi compares for between conditions, for both the time ($n = 15$) and moves ($n = 15$) to check for significant differences between conditions.

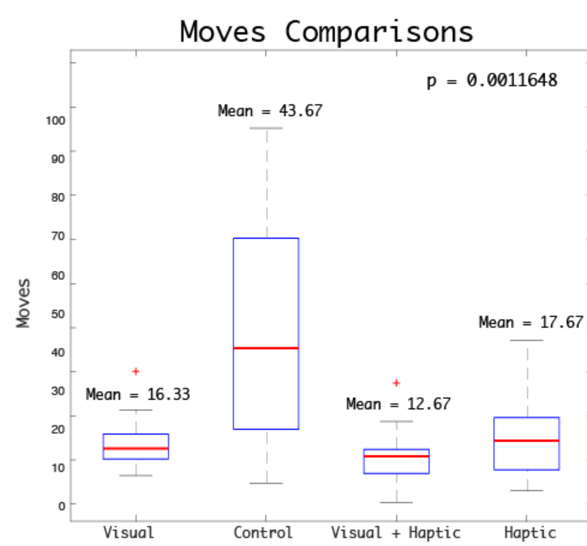

Fig. 3. Box plots for the number of moves for each condition. For comparison between all conditions, $p = 0.0011$, showing significant difference between the conditions. The red asterisks above condition 1 and 3 show they had significant difference from the control (no visual + no haptic). The mean number of moves for each condition are shown by the red lines and listed above each plot.

III. Results

A. The moves needed to find the treasure showed a significant difference between conditions

Overall, the number of moves needed to find the treasure was significantly different between the conditions ($p = 0.0011$, $n = 60$). There was also a significant difference between the control (no visual, no haptic) and the visual and visual + haptic conditions. While the conditions with the visual ques have very similar results, the visual + haptic still performed the best. The comparisons and resulting box plots can be seen in figure 3.

B. There was no significant difference in the time taken to find the treasure

The time counter started as soon as the game opened and ended once the user found the treasure. We found no significant difference for the time, both between conditions and overall. Due to the random nature and cognitive abilities of the participants, this is to be expected. Although it is not a significant difference, the mean time for the visual + haptic condition was still the lowest. The comparisons and resulting box plots can be seen in figure 4.

C. The optimal gaming experience was visual ques and haptic feedback

Each participant stated their preferred game play method following all the trials and conditions. 3 found the visual +

haptic to be the most engaging and easiest way to play, while 2 preferred just the haptic condition. They found the challenge of only haptic to be more fun because ”I like following the stimulation as it gets stronger”.

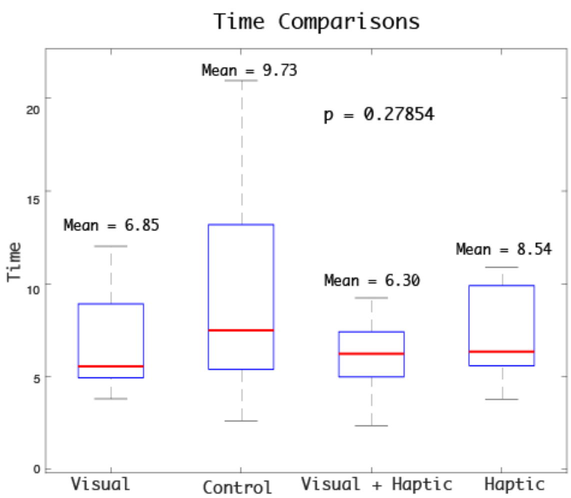

Fig. 4. Box plots for the time to the treasure for each condition. For comparison between all conditions, p = 0.278, showing no significant difference between the conditions. This could be due to the random nature of the game and the cognitive abilities of the participants. The number of moves more clearly illustrates the impact of the conditions.

IV. Discussion

The objective of this study was to understand the impact of haptic feedback and visual ques on gaming abilities and experience. We found that the number of moves significantly decreased when both visual and haptic ques were used. We also found that the majority of participants preferred the visual and haptic, and all participants preferred haptic overall. We did not find a significant difference in the time between the conditions. This could be due to the healthy cognitive nature of our participants and their ability to interchangeably use different ques with no lag time.

Prior work has shown how the gamification of therapies improves adherence and enjoyment for patients. Similarly, the use of multimodal inputs for therapies for cognitive decline patients shows significant improvement in their conditions. In this work, we combined these two ideas to try and maximize the benefits from each.

The work presented here builds off of prior works that involve gamification and multimodal inputs by pulling the two together, into one. We use a simple game to highlight how even in it’s simple form, gamification makes therapies much more enjoyable. This game could be used as a cognitive therapy, by having patients find the treasure by following the directions, or a physical therapy for sensation and finger dexterity. On top of being more enjoyable, this game also maximizes the uses and benefits of bother therapy types. The ability to add and remove inputs to the user allows a more customizable experience that can be used to aid in decreasing cognitive decline.

Future work should deploy the game to a patient population, specifically those with dementia or Alzheimer’s to see how it impacts their cognitive ability and how it impacts their ability to complete the game. This game should also be applied to visually impaired persons to see if their gaming experience is improved with the haptic feedback, compared to other accessible gaming technologies.

This work provides a starting point for another version of multimodal therapies and accessible gaming technology. In its current form, the game can be deployed in cognitive therapies to aid in preventing further decline. Similarly, simply remove the visual ques, and the game becomes an accessible game for visually impaired. This same technology can be applied to much more complex cognitive therapies and also be used for feedback in other situations for visually impaired, not just gaming.

V. Author Contribution

RM wrote the manuscript, game code, and ran stats. CA prepped for the presentation. GO controlled the turning on and off of the StimBox. NP helped design the study.

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