Designing Online Multiplayer Games with Haptically and Virtually Linked Tangible Robots to Enhance Social Interaction in Therapy

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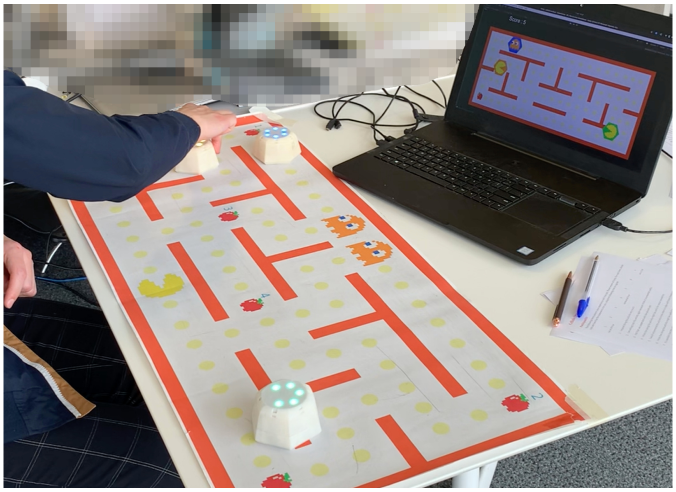

Fig. 1: ”Tangible side” where the patient is playing the game on the physical map by controlling a Pacman. One of the other robots is controlled by the remote player and the last one is an autonomous Ghost.

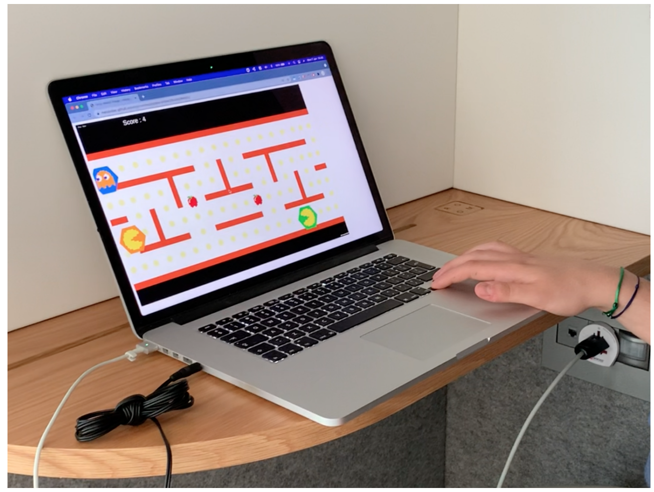

Fig. 2: ”Virtual side” where the remote player controls either a Ghost or the second Pacman depending on the game modality. The virtual representation of the game map and all robots’ synchronized positions appears on both screens.

***Abstract*— The social aspects of therapy and training are important for patients to avoid social isolation and must be considered when designing a platform, especially for home-based rehabilitation. We proposed an online version of the previously proposed tangible Pacman game for upper limb training with haptic-enabled tangible Cellulo robots. Our main objective is to enhance motivation and engagement through social integration and also to form a gamified multiplayer rehabilitation at a distance. Thus, allowing relatives, children, and friends to connect and play with their loved ones while also helping them with their training from anywhere in the world. As well as connecting therapists to their patients through haptically linking capabilities. This is especially relevant when there are social distancing measures which might isolate the elderly population, a majority of all rehabilitation patients.**

I. INTRODUCTION

Psycho-social difficulties such as depression and anxiety may influence seriously the quality of life and lessen the outcomes of therapy and training regimes. Psycho-social well-being can be enhanced through the participation and engagement in meaningful activities beyond oneself, good social relations, and self-esteem, self-acceptance, usefulness and belief in one’s own abilities [1].

Therefore the social and adaptive aspects of a rehabilitation regime are key for patients and must be considered when designing a therapeutic platform, especially for home rehabilitation to avoid isolation. Social and adaptive aspects refer to the ability of the platform to function in multi-user situations, and contribute to maintaining and strengthening cohesion between participants.

Gamified activities have shown to contribute to sense of belonging to a certain place, as well as facilitating conversations between individuals in a social context [2]. Several multiplayer game strategies have been proposed as a promising approach to increase the motivation of patients involved in rehabilitation therapy for cognitive and/or motor impairments [3]. Incorporating social interaction through multiplayer games promotes the enjoyment of the involved players where the additional player adds new possibilities to the game environment, generally missed in single-player gaming against pre-programmed challenges or autonomous agent opponents [4], [5]. The multiplayer game elements can facilitate social interaction with modalities ranging from conversation to haptic interaction and the integration of social interaction is thought to result in better engagement in multiplayer compared to single-player gaming [6]. Therefore, multiplayer gaming has high potential to further increase the

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benefits of robot-assisted neuromuscular and virtual reality-assisted therapy by providing social and physical impacts [1], [3], [7]. Multiplayer games has also the potential to enhance the cognitive activity of the user through generating strategies towards the opponent or while generating joint strategies against the autonomous agents, therefore might improve cognitive functions.

Several studies addressed the added value of the various multiplayer game modalities in rehabilitation therapies, by comparing a competitive to a cooperative mode, or comparing both multiplayer variants to a single-player mode [4], [5], [8], [7], [3], [9], [10]. Some studies also compared effect of the second player being a therapist, a friend or a stranger in multiplayer gaming [8], [5].

Previous research showed that majority of the participants prefer playing a two-player rehabilitation game over a single player game play since multi-user version allows communicating and interacting with the other person. However, the preferred inter-player interaction modality depends strongly on the interests of each participant as well as their co-player [4], [5]. Therefore, in order to provide an effective and adaptive therapy practice promoting social interaction, games should create opportunities for various inter-player interactions through multiple options of game modalities in order to adapt various patients' interests.

Furthermore, patients who exercise together with an unimpaired friend or relative in home environment are much more likely to enjoy some multiplayer modalities than those who exercise together with their therapists [5]. Such multiplayer solutions have strong potential for rehabilitation, as they result in higher enjoyment and exercise intensity than exercising alone [5].

A. *Our Contribution*

In light of previous research, we propose an online version of our previously proposed tangible Pacman game [11] in order to enhance motivation and aim to promote psycho-social well-being through social integration in home-based therapy. We provide gamified multiplayer rehabilitation over a distance where relatives, children, and friends connect and play with their loved ones. Concurrently, this supports them with their therapy or training together from anywhere in the world through the internet which is especially relevant in view of possible social distancing measures isolating the elderly population which forms the majority of all rehabilitation patients.

Additionally, we believe the system might foster inter-generational connectivity, a growing research area since elderly people are increasingly at risk of social isolation and loneliness, due to decrease in intergenerational family and community interactions caused by changes in trends such as globalisation and immigration [12].

The purpose of our proposed design up to this point was to easily allow these people in need of therapy (e.g. stroke survivors) or physical training (e.g. healthy elderly) have the tangible training system with palm-sized Cellulo robots and activity maps readily and physically available to them [11], [13]. However, their loved ones who are at a distance may not have their own set of Cellulo hardware readily available to them. Therefore, throughout this design process, a large emphasis has been placed on simplicity and adaptability in the form of various possible user interactions through virtual links, haptic links, and a range of inter-player interaction modalities. The only virtual link allows the persons not in need of therapy to still be able to play together with their loved ones under therapy using only a laptop while haptic link allows creating a haptic link between people with the tangible system on the both sides. We believe tangible to tangible interaction might also allow therapists to connect with their patients through the gamified platform's haptic linking and/or monitor their home-based therapy online.

II. Design of Online Multiplayer Games

A. *Software Platform*

In this specific research effort, the development focus becomes a virtual online game, in addition to a tangible game. Virtual games are indeed "video games" in the true sense of the word, and a video game engine would benefit our effort in building the virtual and online software elements. For this purpose, we choose the Unity Game Engine[1] for a number of reasons:

- Cross-platform, including desktop, mobile, web, gaming console and VR platforms
- Highly popular at the time of writing, with large pre-existing game developer base
- Key tools and plugins readily available, such as networking components

We integrated the Cellulo robot API as a plugin [2] to Unity, which makes each connected robot a usable game object with a virtual representation. We further benefited from the Photon Engine[3] to provide easy and straightforward real-time data exchange to enable online multiplayer gaming. Photon has strong Unity integration readily available, and allows the creation of "rooms" to host game sessions where players' data are synchronized.

In the resulting game application, the player can either create or join an online game room by entering the specific room name. Before the room is created, the master player chooses the room features such as the game modality and parameters. The other players can connect to the room through the standalone Unity game application or with a web link through their internet browsers, which uses WebGL[4] as a graphics backend and no extra software needs to be installed on a modern browser. After joining the created room, and specifying to be ready to play, the master player sees the total number of players who are ready and starts the game for all players at same time.

In this design, it is key to obtain certain information from the players such as motion data. However, in this instance,

[1] `https://www.unity.com/`, accessed March 2022.

[2] `https://github.com/chili-epfl/cellulo-unity-plugins`

[3] `https://www.photonengine.com/`, accessed March 2022.

[4] `https://www.khronos.org/webgl/`, accessed March 2022.

we have the advantage of being readily connected to online services. Therefore, a cloud data logging module is integrated to the game that sends log files to a cloud storage folder (Google Drive[5] in our instance, which has readily available Unity integration), in order to make it available for the therapists or researchers. Due to data privacy concerns, the log module is made optional. At the end of the game, each player can optionally press a button to send the data file to the cloud storage folder and an option is also available to allow the automatic sending of the logs if desired. This allows to collect and synchronize logs from all remote players, which would be challenging with a local storage-only method.

Since the game is meant to promote social interaction, all of the designed versions of the game are intended to be played together with a video chat session (e.g Zoom[6]), allowing participants to communicate as naturally as possible. This allows them to for example discuss strategies in collaborative game modalities, or playfully taunt each other in competitive game modalities.

B. Game Design Rationale

In the online game, we implemented collaborative and competitive inter player interaction modalities to suit different interests and personalities of the players, and to create different motion strategies. However, a second important dimension to be considered is the tangible properties of the game. In the current design effort, there are two distinct player sides to be considered separately in terms of tangibility. First is the side of the patient or person in need of physical exercise. The tangible aspects of our system allows an intuitive game experience for these people through the rehabilitation training, and physicality key for invoking the actual exercise which is the source of the rehabilitation benefits. Therefore, keeping the tangible gaming elements with real robots and maps is essential for the affected person's use. Therefore for the patient's side of the game we kept the tangible gaming platform with physical maps and the real robots.

The second is the side of the therapist or the affected person's loved ones such as friends or family who wish to play together to improve the affected person's exercise benefits and connect with them. As stated before, these people are considered to be at a distance to the affected person, which makes it a design goal to allow these people to play in the most convenient and readily available manner possible. Therefore, we envision two versions of the remote interaction here to allow this second class of people to readily connect and play, with or without the need for having the robotic platform on their side: align=left

- *Virtual-to-Tangible Interaction:* Envisioned mainly for the loved one to the affected person interaction, in order to remove the need for the remote loved one to have the robotic platform available to them. With the convenience of a single web link, we aim for the loved ones, who are likely young, to be motivated and play more frequently with their affected relatives, who are likely elderly.
- *Tangible-to-Tangible Interaction:* Envisioned mainly for the therapist-to-patient interaction, in order to preserve the haptic link between the two parties even though they are remote. The tangible connection between the therapists and the patients where the therapist can interfere the training by holding the patient's hand was observed to be crucial for the therapist's during the previous testing in the therapy centers [11], and with the haptic linking option this might be possible in some extent by feeling the motion of the patient. Independent of the target user group, recent research on socially connected game experience suggest to consider augmenting the shared tabletop space with connected tangible components for a better online social game experience [14].

Design of these two game concepts with multiple interplayer interaction modalities are explained in detail in the next session.

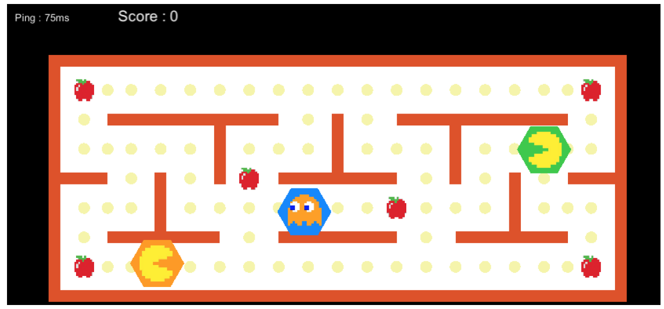

Fig. 3: An example virtual representation of the game map and robots on the game screens of both players.

C. Game with Virtual-to-Tangible Interaction

In this interaction, the affected person's side is the tangible side of the game and the affected person's laptop computer acts as the main controller for the game where the robots are connected. Please see Figure 1 for an example game scene from the tangible side of the online game.

The patient controls the position of his robot by physically moving the robot on the printed map while the other robot(s) is (are) autonomous or controlled by a remote player. The virtual representation of the game maps and all of the robots' synchronized positions appear on the screen of the patient (an example virtual representation appears as in Figure 3). LEDs on the robot also correspond to the colors of the robots displayed on the screen to easily identify which robot has which role in the game.

The remote player connects to the game either using a web link or through a local copy of the game software. They remotely controls one robot at a distance using the computer's keyboard (arrow keys) and can see the game map and the robots' synchronized positions on the screen, similar to the affected person's screen (see Figure 2 for an example

[5] `https://drive.google.com/`, accessed March 2022.
[6] `https://zoom.us/`, accessed March 2022.

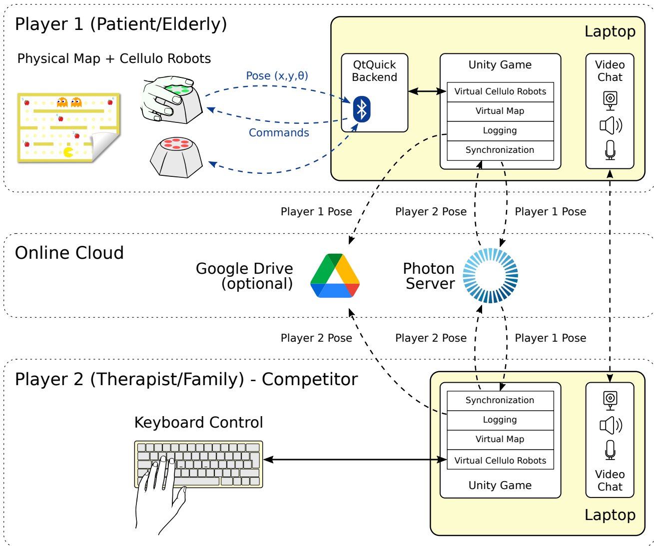

Fig. 4: The software architecture of the competitive game modality in virtual-to-tangible interaction. Player 1 (affected person) controls his/her Pacman (in green, held by the player) to collect the apples on the tangible side of the online game while Player 2 (therapist, family or friend) controls a Ghost robot (in red) remotely via their keyboard on the virtual side of the game. Game state and robot poses are displayed to the second player via the computer screen. Player poses are synchronized over a Photon server and are optionally logged at a cloud storage service such as Google Drive. A video chat session is enabled throughout the game to improve social interaction.

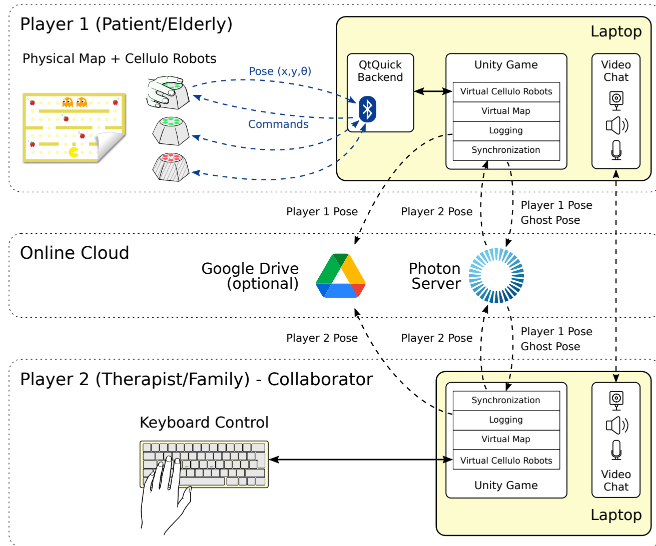

Fig. 5: The software architecture of the collaborative game modality in virtual-to-tangible interaction. Player 1 (affected person) controls his/her Pacman (the robot in green and held by the player) on the tangible side of the game while Player 2 (therapist, family or friend) controls another Pacman (the free robot in green) via his/her keyboard and together they try to collect the apples. An autonomous Ghost robot (marked with stripes and in red) tries to catch the closest Pacman. Game state and robot poses are displayed to second player via the computer screen. Player and Ghost poses are synchronized over a Photon server and are optionally logged at a cloud storage service such as Google Drive. A video chat session is enabled throughout the game to improve social interaction.

game scene from the virtual side of the online game.) In order to stop the remotely controlled robot from exiting the physical game map, which could potentially cause it to fall from the edge of the table on which the tangible game is played, the outer walls of the map are programmed to totally restrict the movement if the remotely controlled robot is pushed towards an outer wall.

Since the virtual-to-tangible interaction modality allows it, we have designed two distinct game modalities, which are competitive and collaborative.

In both game modalities, there are two teams: the Pacman(s) and the Ghost, who have identical goals and game win conditions to our previous designs [11] where Pacman(s) try to collect(s) all apples, Ghost chases the Pacman(s) to catch and eat all their apples, game ends when all apples are collected. Specifically, the use of the concept of ”lives” is undesirable as the game is meant to be played by patients. To maintain an element of challenge, the total time to win the game is displayed when the game is won, which is meant to challenge players to beat their record and replay the game to try to beat it faster and faster. The game timer starts when a Pacman collects an apple for the first time. Below, we explain each game modality:

1) Competitive Game Modality:: The competitive game modality in virtual-to-tangible interaction only requires 2 physical Cellulo robots on the tangible side. Here, the affected person controls the Pacman and the remote player controls the Ghost robot remotely via keyboard. As usual, the Ghost tries to stop the Pacman from collecting all the apples for as long as possible. The game never ends with the affected person losing the game, the timer simply runs unlimitedly until the affected person wins by collecting all apples. The software architecture of the competitive game modality in virtual-to-tangible interaction can be seen in Figure 4.

2) Collaborative Game Modality:: The collaborative game modality requires 3 physical Cellulo robots on the tangible side. Here, both the affected person and the remote player controls his/her own Pacman. They collaboratively collect the apples in the Semi-Dependent modality and the autonomous Ghost robot chases the closest Pacman with the shortest path algorithm. Again, as before, the team of Pacmans ultimately never lose, and eventually win by collecting all apples. The software architecture of the collaborative game modality in virtual-to-tangible interaction can be seen in Figure 5.

D. Game with Tangible-to-Tangible Interaction

In the tangible-to-tangible interaction, each user is required to have the Cellulo hardware, i.e a printed map and

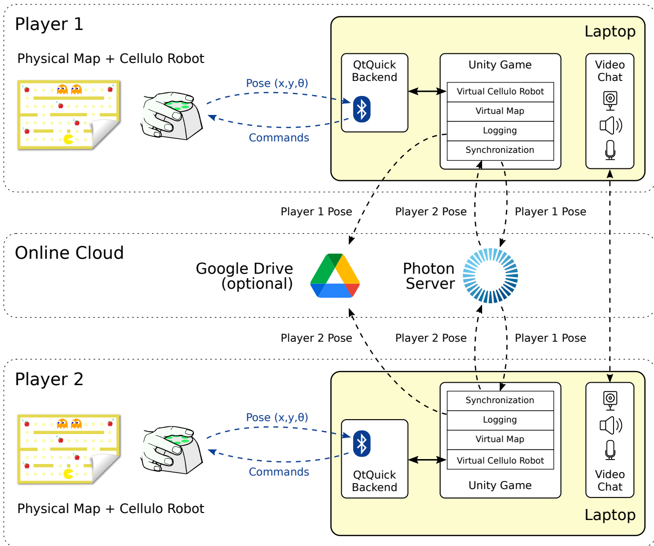

Fig. 6: Software architecture of the online game in tangible to tangible interaction. Two players control one Pacman each and play collaboratively to collect all apples. The two players must find each other and meet on top of an apple to collect it. As soon as players are close, they are "haptically linked", i.e their robots are drawn to one another. Player poses are synchronized over a Photon server and are optionally logged at a cloud storage service such as Google Drive. A video chat session is enabled throughout the game to improve social interaction.

a physical robot, on their side. As a result, each player controls their robot by hand and follows the game on the screen (see Figure 6 for the envisioned software architecture of this interaction modality). In our initial design to make feel the behavior of the affected person by the therapists, we implemented a collaborative game modality by haptically linking the two players who have the common goal of collecting all of the apples. This modality is envisioned to support therapists to intervene the exercise sessions since as stated in our previous studies conducted in rehabilitation centers [11], it is important for therapist to intervene the therapy process and propose adaptations accordingly.

The game starts with the two Pacman robots belonging to the two players in random positions. At the first stage of the game, the players don't see each other on the screen and must find their teammate. Here, the idea is to make use of the haptic feedback feature in order to enable this, for which two distinct methods were implemented: (1) Vibration intensity indicates how far we are from our teammate, and (2) An increasing force feedback in the direction of the teammate to indicate their position.

Once the players find each other, the second phase of the game starts: A haptic link is created between the two players, which constrains their movements by drawing their robots to one another, as if with a "virtual spring". With this link created, the players have to collect the apples on the map, while keeping their link. The targets cannot be collected if the link is not yet created or is broken afterwards by moving too far away from the teammate (which lets the game fall back to phase one). The ghost robot tries to catch a Pacman. If the ghost hits a player or the link, the link disappears and has to be created again.

III. Pilot Experimental Evaluation of Virtual-to-Tangible Interaction

A pilot experiment was held with healthy young adults to gather data and feedback on the game and their written consents are taken before the experiment. 10 participants, in 5 pairs of 2 players, played 2 to 4 games in both game modalities. Every participant played on both the tangible side and virtual side of the game, at least twice per modality. In total, 20 games in the competitive and 21 games in the collaborative modality were played. The games were all played on a single large map to simplify the dimensions of the experiment. In order to reduce the lag by improving bandwidth, the video stream of the online chat was switched off and only the voice stream was left operational. Participants were all healthy individuals with ages ranging from 20 to 40 years old. The players were placed in separate rooms and could only communicate through voice chat to simulate the conditions that the game is intended to be played in.

Each game's duration and number of times the Ghost catches a Pacman during a game was logged, and participants were given a survey about their thoughts on the game at the end of the experiment. The survey includes seven 7-Likert-Scale questions on enjoyment, perceived usefulness and perceived collaboration (see Table I for the questions) as well as two open questions: (1) "Could you please share your comments on the game, game modalities and interaction with the robots?" and (2) "Could you please share your comments on interaction between players?"

IV. Results

Highly positive feedback was received in the questionnaires and participants found the online game modalities fun and intuitive. The Likert-scale questionnaire results suggest that participants enjoyed the game and perceived it as useful for gamified rehabilitation, home-rehabilitation and social connection. They also gave positive responses in recommending this system to the elderly people (see Table I).

A summary of the participants responses to open ended questions are shown in Table II and Table III. Apart from the positive comments, participants did also mention room for improvement. It was observed that there was a lag recognizable by some of the remote players. Furthermore, several players commented that inner walls of the map should serve more than just a visual purpose and penalties for traversing them should be added. The comments also highlight that the Ghost was too slow at times while controlling it remotely. Previously designed configurable game elements [11] (adjustable Ghost speed, wall crash penalty) have the potential to address these shortcomings. Finally, the lack of the video stream that we had to disable in the realistic experiment setting was noticed by one participant. This highlights the

Question	Average response
I enjoyed doing the activity very much	6.9
I am willing to do this activity again because I think it is somewhat useful	6.1
I felt that we cooperated with the second user	6.4
I think that doing this activity might be useful for social connection	6.6
I would recommend this activity to the elderly to play with their friends/grandchildren etc.	6.7
I think that doing this activity might be useful for arm rehabilitation at home	6.7
It is possible that this activity could be useful to improve the rehabilitation process of friends/family	6.4

TABLE I: Qualitative survey results with mean response of the 10 participants on a 0-7 scale, 0 being "Not at all true", 7 being "Very true".

Frequency	Comment
4	"Intuitive and user-friendly interface"
4	"There is a lag on the virtual side"
3	"Great approach with the two different game modalities"
3	"Interaction with the robot felt natural"
3	"Competitive modality was the most fun"
3	"Should add rules for penalizing trespassing walls"
2	"Ghost speed should be adjustable or dynamic"
2	"Integration of physical map and game was seamless"
1	"Robot manipulation shows its potential use for rehabilitation"

TABLE II: Summary of the participant responses to the question: "Could you please share your comments on the game, game modalities and interaction with the robots?"

Frequency	Comment
4	"Had much fun laughing and playing with friends"
2	"Collaborative modality encouraged communication and group coordination"
1	"Interaction through both the game and voice chat bring players together and enhances both game modalities"
1	"Enjoyed the nostalgic feeling of playing Pacman"
1	"Adding a video stream and displaying player names would improve social connection"

TABLE III: Summary of the participant responses to question: "Could you please share your comments on interaction between players?"

need for possibly a dedicated and optimized video stream channel that allows for lag-free gameplay instead of an "off-the-shelf" video chat service such as the one we used.

On average the competitive games lasted 47.2 seconds ($SD = 29.1$ seconds) while the collaborative games lasted 40.3 seconds ($SD = 31.9$ seconds). Cooperative games have understandably the tendency to be shorter than competitive games since the two Pacmans in collaborative version can collect the apples faster than single Pacman in the competitive version.

In the competitive modality, players controlling the Pacman got caught 0.36 times per game on average whereas this value is 1.61 for the collaborative modality. This can be explained by the fact that remote players had trouble evading the autonomous Ghost despite its movement speed having been set to be 10% slower than that of the remote player. On the other hand, players controlling the Pacman by hand were observed to quite easily outrun the Ghost. Imposing speed limits or adaptive Ghost speeds might improve this issue in the future. Another explanation for getting caught by the Ghost more often is that there are 2 targets for the ghost to catch, instead of one. Another possible reason might be the limited Ghost speed in competitive games which does not allow for the remote player to catch the Pacman easily, since the Pacman is manually controlled without a speed limit. This issue can potentially be solved by using adaptive ghost speed for the remote player which is proportional to the speed of the Pacman on the tangible side.

Several emergent strategies and behaviours were discovered and adopted by participants during the gameplay to improve their performance. Some pairs played the game and tried not to cheat, whereas other players used all exploits available. Moving the robot by hand at much higher speeds than the robots can reach alone by their locomotion (around 180 mm/s), made games easy for the player on the tangible side. In one instance, the player on the tangible side kidnapped the robot and placed it on the other side of the map in order to avoid the Ghost, resulting in an apparent illegal teleportation of the robot on the game screen.

Another interesting strategy was to defend an apple by blocking the Pacman's path. It went as far as even standing still on top of an apple, completely preventing the Pacman from picking it up. Some players controlling the remote Ghost enjoyed cheating by trespassing the walls which helped to compensate for the slower motion of the Ghost robot.

Tangible-to-tangible interaction is not yet tested with healthy or patient groups since there is an ongoing development of the system to minimize the lag of the robot position synchronization across the players. Indeed, the lag is present and was noticeable during our preliminary experiment on the virtual side of the game. With the current state, the haptic linking has too much delay to be informative and usable over the internet. A new type of competitive modality should also be implemented for the tangible-to-tangible interaction. A promising direction is that each player feels the other's direction but the one who collects more apples wins the game.

V. Conclusion and Discussion

In view of the current social distancing issues, it has become necessary to think about alternative online solutions that would allow to continue rehabilitation training or socially enhanced home-based therapy and training.

In this research effort, we introduced an online multiplayer game with various inter-player interaction modalities, which incorporates remote social interaction into our therapy and exercise regimes. The proposed game is intended to be used as a form of socially enhanced gamified rehabilitation and would allow patients to perform their training while playing and interacting with friends or relatives over the internet with an option of haptic linking.

The proposed online framework was designed in a modular way and preliminary tests were done with the virtual-to-tangible interaction modality to collect feedback. Limited pilot studies were conducted as an experimental verification first step. Since these studies were mostly conducted with healthy young participants, the results do not reflect the performance and results that would normally be obtained from patients or aging users. Although the platform received several positive responses, it needs further improvements to be suitable for testing with target groups. More importantly, as applied in the initial design process of the tangible Pacman game, there is also a need for an iterative design process for online games with with the domain's professionals and people from the target groups for the risk of adoption failure before being able to test the system with the target users as well as in their home environments.

Further improvements include cheating detection, crash penalty rules, robot kidnapping penalty rules, adaptive speed integration for the remote player, and integration of haptic assistive feedback. Most importantly, the position feedback lag in either side of the game must be eliminated, which may be due to extra network layers in the messaging protocol.

Another essential further improvement of the current proposed multiplayer games is the adaptation of the task difficulty to each individual in order to facilitate a balance between the patients and their healthy opponents. In gamified rehabilitation environments, this adaptation is an important challenge due to the large variability in cognitive abilities and motor skills. Therefore, it is crucial to test the systems with the target groups while they are playing against healthy opponents and understand how to manipulate game conditions to balance the skill levels of players and enable multiplayer gaming across affected and non-affected individuals.

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