Designing Spellcasters from Clinician Perspectives: A Customizable Gesture-Based Immersive Virtual Reality Game for Stroke Rehabilitation

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Developing games is time-consuming and costly. Overly clinical therapy games run the risk of being boring, which defeats the purpose of using games to motivate healing in the first place [10, 23]. In this work, we adapt and repurpose an existing immersive virtual reality (iVR) game, Spellcasters, originally designed purely for entertainment for use as a stroke rehabilitation game—which is particularly relevant in the wake of COVID-19, where telehealth solutions are increasingly needed [4]. In preparation for participatory design sessions with stroke survivors, we collaborate with 14 medical professionals to ensure Spellcasters is safe and therapeutically valid for clinical adoption. We present our novel VR sandbox implementation that allows medical professionals to customize appropriate gestures and interactions for each patient's unique needs. Additionally, we share a co-designed companion app prototype based on clinicians' preferred data reporting mechanisms for telehealth. We discuss insights about adapting and repurposing entertainment games as serious games for health, features that clinicians value, and the potential broader impacts of applications like Spellcasters for stroke management.

CCS Concepts: • **Human-centered computing → Accessibility design and evaluation methods**; **User studies;**

Additional Key Words and Phrases: Stroke rehabilitation, digital therapeutics, therapy, immersive virtual reality, game design, games for health, serious games

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1 INTRODUCTION

According to The **National Institute of Neurological Disorders and Stroke** (**NINDS**), a component of the U.S. **National Institutes of Health** (**NIH**), more than 800,000 people suffer a stroke each year in the United States alone, and approximately two-thirds of these individuals survive

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Fig. 1. Screenshot of Spellcasters, featuring spell-casting gestures and virtual environment.

and require rehabilitation [60]. Stroke is a leading cause of serious long-term disability [80]. Moreover, the stroke management market size was valued at 30.1 billion American dollars in 2019 and is expected to witness a 6.3% compound annual growth rate from 2020 to 2026 [79]. In the wake of COVID-19, telehealth solutions have become increasingly relevant for delivering scalable remote healthcare solutions to curb the spread of the virus [4, 5, 86]. Stroke physical and occupational rehabilitation typically requires long-term and consistent intervention [45] with many challenges to keep stroke survivors motivated [51]—a unique challenge that games have successfully navigated in many contexts [64, 69, 83] including mental health (e.g., [55]), physical health (e.g., [6, 30, 37, 54, 57, 66]), and speech therapy (e.g., [24]).

Potential benefits of repurposing existing entertainment games for therapy include reduced costs and development times with some promise for appropriating already-fun mechanics [23]. During a global pandemic, when telehealth solutions are needed quickly, appropriating technology to serve a new purpose is particularly relevant. In this work, we explore the adaption and redesign of Spellcasters, shown in Figure 1, an **immersive virtual reality** (**iVR**) game where wizards cast spells by making gestures with their wand (VR controller). The original implementation of Spellcasters is designed purely for entertainment, but the gesture-based spell-casting mechanic is intriguing because it shares many commonalities with upper limb rehabilitation exercises, including repetitions, accurate movements, and varying range of motions that can be measured using motion tracking. Placing stroke survivors in VR has risks, so we begin our participatory approach by collaborating with 14 medical professionals to validate that Spellcasters is safe and medically vetted before co-designing with stroke survivors. To this end, we co-design an open environment for physical therapists and occupational therapists to create custom gestures for their patients to "cast" and collect preferences on features for optimizing Spellcasters for telehealth, including performance monitoring and goal setting. In this work, to protect stroke survivors from contracting the COVID-19 virus during the pandemic and from using untested non-specialized software, we focus on designing elements of Spellcasters that will be primarily used by medical professionals—namely a custom gesture creation sandbox for defining individualized stroke exercises (described in Section 4.1) and a companion app for remote monitoring and administration (described in Section 4.5). These developments could be generalized to other game domains beyond casting spells in future participatory work with stroke survivors.

The contributions of this work are 3-fold: (1) We contribute to a growing body of work that advocates for scalable telehealth games for affordable and equitable access to healthcare, (2) we provide insights from collaborating with medical professionals on how serious games for health can support custom and adaptable physical therapy curriculum remotely, and (3) we share auto-ethnographic reflections on adapting existing games for therapy and including medical stakeholders in remote participatory design sessions.

2 BACKGROUND

This section introduces what traditional stroke management and rehabilitation entail, related works using VR for stroke rehabilitation we are inspired by, and an argument for serious games for health as a potential solution space for scalable, customizable, and equitable healthcare delivery.

2.1 Stroke Rehabilitation

Stroke survivors often experience a range of impairments, including loss of balance, cognitive deficiencies, pain, weakness, and paralysis—resulting in challenges performing everyday activities such as bathing, eating, walking, and cooking [76]. In most cases, these effects of stroke are present on one side of the body, known as hemiparesis [11]. Even though rehabilitation does not reverse brain damage, it can substantially help people achieve the best possible long-term outcome [45]. For some survivors, rehabilitation will be an ongoing process to maintain and refine skills for months or years after the stroke [45]. Stroke survivors tend to avoid using impaired limbs—a behavior called learned non-use. However, the repetitive use of impaired limbs encourages brain plasticity and helps reduce disabilities [85]. In practice, physical and occupational therapy emphasizes performing isolated movements, repeatedly changing from one kind of movement to another, and rehearsing complex movements that require a combination of coordination and balance. A recent trend in stroke rehabilitation emphasizes the effectiveness of engaging in goal-directed activities, such as playing games to promote coordination [60].

There have been many software interventions for stroke rehab (e.g., [3, 15, 17, 27, 47, 58, 66, 72]). Many input modalities have been explored including motion tracking (e.g., using the wii controller [3]), 3D sensors such as the Kinect or the Intel Real Sense (e.g., [58, 70, 84]), keyboards for fine motor control [44], shape-changing robots [47], webcams that track colored objects [3], smartphones that track performance [32], and VR (e.g., [15, 16, 27, 46, 71]). Many of these software interventions are games—we discuss the benefits of using serious games for therapy in the next section. We present more details on VR for stroke rehabilitation in Section 2.3.

2.2 Serious Games for Health

A serious game for health is a game created to entertain and achieve health goals [39]. Games are motivators and make tedious repetition engaging through gameplay [3, 11]. Many serious games have led to improved health outcomes (e.g., [49]). Video games improved 69% of psychological therapy outcomes, 59% of physical therapy outcomes, 50% of physical activity outcomes, 46% of clinician skills outcomes, 42% of health education outcomes, 42% of pain distraction outcomes, and 37% of disease self-management outcomes [65]. Learnability, flexibility, and robustness are core paradigms to creating usable and valuable serious games for health [21]—the ability to customize serious games for health for the heterogeneous needs of stroke survivors is integral to our work.

2.2.1 Customizable Serious Games for Health. It is important that therapy games be customizable because players have individual abilities [13], therapy goals [45], and motivations [52], similar to the concepts of player archetypes [59]. We found Alankus et al.'s insights on multimodal inputs, feedback, and breadth of games inspiring in the stroke rehab games context [3]. We are particularly interested in what medical practitioners find important for custom stroke rehabilitation in this work. There are various types of motions that therapy games designed for the upper extremity should cover; these include: shoulder abduction and adduction, shoulder flexion and extension, shoulder internal and external rotation, elbow flexion and extension, wrist rotation, flexion and extension, hand and finger flexion and extension, grasp, move, release and reaching [3]. 3D depth sensors can track most of these motions [84] as well as VR devices [73] by using the standard motion controller. Not all of these exercises are accessible to each stroke survivor's abilities [45]. In this work, we are interested in leveraging these sensing abilities in ways that are customizable and adaptable to the individual needs of each player. The affordances of scalable technology allow adaptive therapy experiences for telehealth, described below.

2.2.2 Telehealth and Games. Benefits to telehealth interventions such as VR stroke rehab games include scalability [20], increased access [35], customization [20], and rich data-driven insights based on large data sets and artificial intelligence [25]—an approach common in-game user research, called telemetry [22]. In this work, we are particularly interested in the reporting features clinicians are interested in to make informed insights into their patient's progress both at home and outside the clinical setting. Telehealth affords interactive contact, allowing for day-to-day tracking of improvement and modification of recovery plans. The benefits of using telehealth may boost the efficiency of stroke therapy with more prompt and regular evaluations and better consistency across the healthcare chain.

2.2.3 Telehealth and COVID-19. Due to the COVID-19 pandemic, many inpatient rehabilitation facilities and services have emergency preparedness plans in place to curb the spread of the virus, including cancellation of non-required therapies such as physical, speech, and occupational therapy [56]. Medical professionals and patients who have looked towards telehealth opportunities have been met with complex barriers, including limited options and lack of insurance coverage [56].

It can be challenging to include people with disabilities in participatory work generally [82], but there is a specific added risk during a global pandemic. Co-Design sessions should be valuable to all parties [8], but they disrupt everyday life and require participants to invest their precious time. In addition to general guidelines that limit in-person contact, populations of people with disabilities often have medical needs that place them at higher risk from the COVID-19 virus [5]. In light of quarantine, designers are employing creative methodologies to carry out remote design work that is usually done in situ [86] (e.g., using games to educate the public about COVID-19 and collect data [50]). Many of these technologies are not accessible to people with disabilities [4]. To this end, in this work, we focus on co-designing *Spellcasters* with medical professionals to ensure its medical safety and efficacy before working with stroke survivors after the COVID-19 vaccine is widely administered. We concentrate on designing an intuitive environment for medical professionals to create custom and adaptive gestures for their patients' needs as well as tools for tracking and reporting on the progress of telehealth. We argue that drawing inspiration from existing games developed for entertainment provides some insurance that the game will have entertaining mechanics without risking the health of stroke survivors or subjecting them to inaccessible remote protocols. The groundwork for the rehabilitative custom gesture system we develop in this work could be utilized and expanded to domains and themes beyond spell-casting in magical worlds, based on future participatory work with stroke survivors. If, however, stroke survivors enjoy the magical domain, we can contribute further anecdotal examples of the value of appropriating entertainment games for therapy through this design choice that protects the health and well-being of stroke survivors in the current pandemic climate.

2.3 Virtual Reality for Stroke Rehabilitation

VR for physical rehabilitation with stroke has seen an extensive exploration over the past decade due to the potential to use gaming to motivate and guide users through repetitive therapy exercises. iVR refers to the sensation of being physically present in a non-physical environment. The perception is generated by enveloping the user of the VR system with visuals, sounds, or other stimuli that create a complete and engaging experience. Non-immersive virtual reality, unlike iVR, delivers an identical picture to both users' eyes. As a result, people experience this picture in just two dimensions: height and breadth, but fully iVR technology offer a digital image in three dimensions: height, width, and depth. Non-immersive VR games have been explored as early as 2007 with systems such as Microsoft Kinect [58], PlayStation [34], and Nintendo Wii [72], demonstrating feasibility in tracking patient progress and improving compliance through these motion-based controllers. Multiple reviews have suggested that VR-supported mediums for stroke rehabilitation can be effective in improving patient outcomes compared to traditional stroke therapy due to the ability to simulate controlled interactive environments for exercise guidance and quantitative data capture [18, 48, 58]. Moreover, hundreds of studies throughout the past decade support that VR is useful for motor rehabilitation with many reporting significant improvements in compliance and or recovery [12, 14, 27, 30, 42, 58, 72].

In 2021, the consumer market saw widespread adoption of iVR, enabling full-body movement and 360-degree viewing of the virtual world through **head-mounted display** (**HMD**) systems. These systems are becoming increasingly immersive, accurate at capturing human motion, and are projected to reach 30 million sales per year by 2023 [67]. More recently, the academic community has begun investigating the usage of iVR HMDs for post-stroke rehabilitation. Many studies have suggested that iVR HMDs can significantly improve post-stroke standardized upper-extremity motor tests. However, existing evidence is limited as there is a greater need for more studies to investigate the non-pharmacological therapeutic pathway of iVR for people after stroke [62].

There has been a growing interest in translating these motor rehabilitation exercises into iVR games for post-stroke. *Project Star Catcher* has demonstrated that iVR can benefit treatments such as Constraint-Induced Movement Therapy with stroke survivors by increasing compliance up to 40% when compared to traditional methods and providing an accessible medium for capturing patient success metrics with HMD motion capture [27, 29]. *Project Butterfly*, an iVR experience inspired by Mirror Visual Feedback Therapy, has explored the potential to engage patients for long-term treatment with immersive virtual environments, which is vital because stroke rehabilitation can span years [28, 63]. *REINVENT* applied neurofeedback systems to iVR games with promising pilot results suggesting feasible and safe usage for severe stroke upper limb motor recovery [74]. Additionally, some studies have begun testing commercial entertainment-based iVR exercise games (e.g., *Beat Saber*) for users with chronic stroke and found that long-term gameplay can improve patient results for standardized upper extremity motor function tests [31]. While many iVR solutions exist for stroke rehabilitation and suggest promising results, there is an inherent need for more validation within the academic community to investigate iVR HMD-based design and clinician needs [62]. Thus, in this article, we examine the usage of gesture-based exercises for an iVR HMD experience from clinician perspectives by repurposing an entertainment-based game for stroke rehabilitation as a precursor to participatory work with stroke survivors.

3 METHOD

The primary goal of this work was to redesign and adapt an entertainment-based exergame for stroke rehabilitation. In this work, we focus on the intuitive software medical professionals will use for creating custom rehabilitative gestures for their patients' unique and heterogeneous needs. Based on our literature review and initial interviews with physical therapists, we defined three research questions that drove our development and evaluation of *Spellcasters*:

- RQ1: *How do clinicians want to customize the therapy exercises towards an accessible primary spell-casting game mechanic (gesture creation)?*
- RQ2: *What data, visualizations, and reports are clinicians interested in for clinical decision-making?*
- RQ3: *How can Spellcasters support the telehealth needs of the COVID-19 era?*

These contributions aim at ensuring that Spellcasters is safe and medically vetted before engaging in future participatory work with Stroke Survivors for prototyping iterations. The research questions above are exploratory and afford a qualitative and iterative Research through Design approach [36, 88].

Table 1. Participant Demographics

	Sex	Role	State	VR HMD Access	Companion App
P1	M	Physical Therapist	Ohio	✓	X
P2	M	Physical Therapist	Kansas	X	X
P3	M	Physical Therapist	California	X	X
P4	M	Physical Therapist	Minnesota	✓	X
P5	M	Physical Therapist	California	X	X
P6	F	Physical Therapist	Michigan	X	X
P7	M	Physical Therapist	California	X	X
P8	F	Physical Therapist	Virginia	X	X
P9	F	Occupational Therapist	Ohio	✓	X
P10	F	Physical Therapist	New York	X	✓
P11	F	Physical Therapist	New York	X	✓
P12	F	Occupational Therapist	Massachusetts	X	✓
P13	F	Occupational Therapist	Washington D.C.	X	✓
P14	M	Occupational Therapist	Washington D.C.	X	✓
Totals:	7 Female : 7 Male	10 Physical : 4 Occupational	11 Unique	3 Self VR Access	5 Self Companion Access

3.1 Software

Due to the COVID-19 pandemic restrictions, we employed a fully virtualized human subjects protocol completed online over *Zoom*,[1] a video-based teleconferencing platform with screen sharing capabilities. *Spellcasters* is an immersive VR game that requires a HMD system, but not all medical professionals have access to these devices. Consequently, we employed separate procedures for those with and without supported VR HMD systems, described below in Section 3.3. We used *Google Sheets*[2] to analyze and transcribe the recordings, grouped by interview questions (included in our supplementary materials and live at https://tinyurl.com/Spellcasters-Supplementary). A shared executable file of the game's build was given to all participants who had access to a VR system during the interviews. Additionally, a mockup interface was shared through *Figma*,[3] an industry-standard software for rapid prototyping of user interfaces, to iterate and evaluate a companion app described in the *Spellcasters* Section 4.

3.2 Participants

The participants recruited in this study consisted of physical and occupational therapists with experience in post-stroke rehabilitation. Recruitment was conducted by reaching out to medical professionals in rehabilitation leadership positions (e.g., chapter presidents of the United States American Physical Therapy Association[4]) followed by Snowball recruiting [40] and posting recruitment fliers on social media groups for rehabilitation. Through this process, 14 medical professionals were recruited to participate in this study, with corresponding demographics illustrated in Table 1.

3.3 labelProcedures

With the consent of the participants, all virtual interviews were recorded for post-analysis, with each session lasting between one to two hours (with all materials used in the procedure of evaluating *Spellcasters* shared at https://tinyurl.com/Spellcasters-Supplementary). Sessions began with a set of preliminary semi-structured interview questions inspired by [22] to understand each medical professional's experience and practices related to stroke recovery. We included questions

[1] https://zoom.us/.
[2] https://www.google.com/sheets/about/.
[3] https://www.figma.com/.
[4] https://www.apta.org/.

related to their openness, experience, and expectations for physical therapy games (*RQ1*). We asked how they currently collect data, communicate with insurance providers, and set goals (*RQ2*). Pre-surveys were concluded with questions on how COVID-19 has changed their practice if they have adopted telehealth and reflections on if and how they measured progress made by patients outside of their appointments (*RQ3*).

After the preliminary interview, participants experienced *Spellcasters* either directly with their own VR HMD or indirectly by seeing a mirror of the research teams' HMD view. In both cases, gameplay and user interaction were mirrored in video using the *Zoom* screen sharing feature so everyone could see the game and record the gameplay for later analysis (including game audio). Medical professionals without VR HMDs were asked to instruct the researcher on how to play similar to a Think Aloud protocol [22] (*RQ1*).

As the Research through Design process progressed, it became clear that the medical professionals would benefit from a companion app, described in Section 4.5 (*RQ2*, *RQ3*). Subsequently, the procedure was adapted to explore this interaction for *Spellcasters*, where participants tested a companion app designed in Figma using the Think Aloud protocol [22]. Participants freely explored the app during this phase, provided initial impressions, discussed confusing elements, and shared design recommendations. We were particularly interested in the data visualizations medical professionals were interested in (*RQ2*), so we asked participants to describe how they interpret each graph, asked them if there was a more appropriate format they prefer, and if there were any elements that could be added to make the graphs more intuitive. We iterated on the Figma prototype between sessions to incorporate each participants' feedback. We continued this cascading iterative process until a critical mass of participants could understand the graphs and found them intuitive and valuable.

Finally, participants were asked a set of closing semi-structured interview questions [22] (*RQ1*, *RQ2*, *RQ3*), provided at https://tinyurl.com/Spellcasters-Supplementary, so that we could evaluate the prototypes and recruit more participants. After each session, the game and companion app prototypes were iterated based on observations and feedback. The highly iterative Research through Design approach led to many insights towards answering our research questions.

After completing all research through design sessions, medical professionals were asked to complete a follow-up survey. eight out of 14 completed the survey. We included the Spellcasters trailer in the survey to highlight the iterative updates to the game since their playtest. The Figma prototype was also linked in the survey so the participants could experience the most up-to-date version. The survey consisted of nine Likert questions asking participants to rate how much they disagreed or agreed with the nine statements.

All of our transcriptions and summaries are available in the supplemental materials for transparency here: https://tinyurl.com/Spellcasters-Supplementary. We sorted responses for each question by each participant in a document table that includes summaries of each question, giving equal weight to all feedback. In our results section, we organized these summaries into themes inductively, taking careful precautions to reduce bias by including both positive and negative feedback from our participants.

3.4 Ethics

This research was reviewed and approved by the institutional ethics review board. An important consideration was COVID-19 and the added risk many stroke survivors would face if they participated in this research—both in-person and remotely. In-person protocols would be hazardous because they would place stroke survivors at risk of infection. However, remote participation is also dangerous because the software many of us have come to rely on during the pandemic is not accessible [5] and without medical supervision, playtesting, and co-designing *Spellcasters* before it is medically vetted could also result in injury. Our institutional ethics board mandated that we first work with medical professionals before designing and testing with stroke survivors, which we agree protects stroke survivors from unnecessary risk during the pandemic. We believe including people with disabilities early and often in the design process is critical, which we will discuss in the next paragraph. However, given the circumstances of the pandemic, we decided to work exclusively with medical professionals and leave the game world open-ended for future participatory work with stroke survivors once the vaccine has been widely administered.

Over a decade ago, ASSETS scholars called for the use of a critical disability lens while designing and developing assistive technology for disabled individuals [53]. This call has only strengthened in the proceeding years, with an emphasis on allowing for more co-design and co-research with disabled people [7, 75, 87]. To summarize the concern, the majority of assistive technology devices and applications are rooted in medical discourse. That is, disability is an inherent problem in the body and must be “fixed” or “normalized” by intervention. Using a more socially-oriented lens, such as those found in disability studies, emphasizes the social context and environment as *creating* disability by denying access to particular body configurations [38, 68, 78]. Given this concern about the discourses that influence the design of assistive technologies, it has become even more important for researchers to acknowledge the needs of the disabled individuals the technology is meant to help. We intend to include stroke survivors in the design process for the gameplay surrounding casting the gestures made by medical professionals in future work. We chose magic wands because the possibility space remains open for stroke survivors to choose further game directions. The Results section provides evidence that supports the magical spell-casting domain we have appropriated from the pure entertainment version of the game. However, if stroke survivors imagine other domains during our participatory design sessions, the gesture recognition system and environment for medical professionals to create custom exercises could easily be generalized to new domains.

Designing serious games for medical use is complicated due to the ethical responsibility that it entails. Specific game mechanics may seem fun to play, yet a poorly designed game may cause more harm when used practically with impaired users. As designers, we need to conduct research and trials to ensure our design suits our target audience. While designing Spellcasters, we have worked closely with medical practitioners to evaluate what set of features are needed and valuable for stroke survivors. From our research, we found that strokes are affecting increasing in younger populations. One medical practitioner (PT8) expressed that they treat stroke patients as young as five. Given this concern, our team studied pre-existing games and stories such as; Waltz of the Wizard and Harry Potter—popular themes among younger generations. With the help of physical therapists, we can design our spells to resemble traditional therapy while maintaining an engaging experience. We envision this game supporting rather than replacing traditional physical therapy. With this game, we hope to help engage and motivate the stroke survivors to do their rehabilitation exercises prescribed to them more often because consistency and compliance are critical to their recovery.

4 SPELLCASTERS

Spellcasters[5] is an immersive virtual experience designed in the *Unreal Game Engine*[6] *(v4.24.3)* that was repurposed from an entertainment-based exergame to a medically informed therapy game for stroke survivors. *Spellcasters* was originally a game purely for entertainment where two teams of 5 wizards competed in a magical duel. Wizards had various roles on their team, such as tank,

[5]Spellcasters Trailer: https://tinyurl.com/Spellcasters-Trailer.
[6]https://www.unrealengine.com/.

support, and melee—each with a corresponding spellbook and spells. Both teams had a pool of lives, and the last team standing won the round. The entertainment version of *Spellcasters* was developed in Unity and used an off-the-shelf machine learning-based gesture recognition system. When the stroke rehabilitation version of the *Spellcasters* project began, approximately a year after the entertainment version was completed, we realized the underlying gesture products were no longer supported and were difficult to train with new gestures. We found no alternative products that would meet our needs, so we decided to build an intuitive gesture creation system so medical professionals could create custom therapy exercises. The novelty of Spellcasters lies in this custom rehabilitative gesture system we have designed, described in Section 4.1. Around the same time, we met with industry leaders developing specialized VR hardware for physical rehabilitation that required the additional processing power of Unreal Engine. To keep future potential partnership opportunities open, we chose to rebuild a rehabilitation version of Spellcasters in Unreal Engine—creating a custom gesture system and removing the competitive multiplayer features from the original game (for now). Reusing design documents, art styles, media, and drawing inspiration from the entertainment version of the game made development much smoother—even in a new game engine. Our focus turned to making *Spellcasters* medically vetted while the pandemic made participatory work with stroke survivors unsafe. To this end, we worked on designing and implementing the gesture creation system and an accessible spell-casting experience. We left the game world an open sandbox so stroke survivors could inspire future development directions when participatory work is safe or when teleconferencing tools become more accessible.

We have access to the full source code through the serious games masters program at the University of California Santa Cruz—a rare opportunity which we discuss in Section 6. The onset of transitioning the game for therapy purposes began with obvious accessibility updates based on heuristics [19] and tacit knowledge from the research team, including simplified and more legible user interface elements and multimodal audio, visual, and haptic feedback. For example, instead of a text-based menu, we created a magical office space where virtual objects represent the menu options (e.g., wizard hats for jumping to various levels and a magic spellbook with game options, such as audio settings and accessibility feature toggles). Another example is the addition of the fairy companion, a guide who contextually gives instructions and hints via subtitled verbal instructions. We reduced the amount of text, made text larger, and offered alternatives to text in the form of contextual cues and instructions given by the fairy companion who serves as a guide in the game. Early in the process, we began interviewing physical therapists and occupational therapists working with stroke survivors to collect functional requirements for the core therapeutic spell-casting mechanic. The medical professionals wanted the ability to create custom spell gestures for the idiosyncratic needs of their patients with 6 degrees of freedom (Section 4.1; Related to *RQ1*), the ability to set which hand is used for casting for patients with hemiparesis and isolate movement (Section 4.3; Related to *RQ1*), the ability to play seated or standing for safety (Section 4.3; Related to *RQ1*, *RQ3*), and the ability use data-driven insights to customize rehabilitation curricula, insurance reports, and manage patients (Section 4.5; Related to *RQ2*, *RQ3*). Many of these requirements echo the framework presented by Saini et al, including varying levels of difficulty, precise direction, display feedback, and time limitations [70]. A playable build of *Spellcasters* can be found at https://tinyurl.com/Spellcasters-Build.

4.1 Custom Gesture Creation

We developed a novel custom gesture creation system that allows clinicians to create exercises in the form of 3D-enabled magical spells. These spells can be customized using an intuitive point and click mechanic capable of recording therapeutically relevant variables, including scale, shape, direction, and depth, depending on the motion the clinicians want the patient to perform (depicted

Fig. 2. Process of creating custom exercises for stroke survivors as magical spells in a virtual environment including sphere placement, reward selection, and repetition setting.

in Figures 2 and 3). For example, a clinician may design a small circle by placing the spheres close together—useful for wrist rotation exercises. In contrast, a larger circle would require the stroke survivor to use their whole arm for an external rotation exercise. This feature gives clinicians creative freedom and endless possibilities for designing and customizing their gestures. To create a spell, a clinician must decide and place a series of collision spheres, which creates a specific shape. The order that the clinicians place the spheres determines the sequence in which the stroke survivor needs to connect them to complete the gesture (Shown in Figure 3). The clinician can set repetition counts of these gestures and what this spell does for patients (Shown in Figure 2). Each spell effect helps provide a sense of purpose to each patient's successful attempt to perform a gesture. It also shows the patient's progress during the session as one can see and count the number of trees or flowers a patient might have planted by the end of the session. These repetition counts are shown on the spellbook value, indicating how many times the patients need to do them successfully, shown in Figure 4.

Using a participatory approach during our design sessions with medical professionals, we co-designed a set of predefined gestures that *Spellcasters* will support by default. The resulting 18 predefined spell gestures include a horizontal line, vertical line, diagonal line, rectangle, square, triangle, semi-circle arcs, circles, and infinity symbol. Medical professionals helped us inductively sort these gestures into relevant non-mutually exclusive themes, including "Extending Arm," "Rotation," "Internal Rotation," "External Rotation," "Crossing Mid-line," and "Raising Arm." This design feature is related to *RQ1*. The spellbook, shown in Figure 4, is stocked with these predefined spells and displays a subset of relevant themes.

4.2 Gesture Tracing

For a player to cast a spell, they begin by flipping through pages of the spellbook until they find one they would like to cast—the active spellbook page signals to the custom gesture recognition system, which guides the player on how to trace the shape that appears in front of them. Tracing the spell requires the stroke survivor to point their wand and contact the depth-sensitive spheres in the correct order. Using a participatory approach, we co-designed an initial set of user experience features to make gesture tracing accessible to the stroke survivor, including haptic feedback for when the player starts to veer off the path, spheres that indicate order by growing and shrinking as the player progresses through the points, thick green lines with arrows between the points to illustrate the "target threshold zone" and direction, verbal feedback from the fairy, sound effects for successful and failed attempts and a tracking line that visually traces the stroke survivors path from the tip of the wand. Many of these features can be seen in Figures 4 and 5. Additionally, we created contextual videos that pop up and demonstrate to players the various aspects of the spell-tracing mechanic, shown in Figure 4. Once the gesture is successfully traced, patients can cast the spell by pressing a button to point and shoot at a given location. If the patient wants to cast the spell somewhere other than where they are located in the scene, they can press a button to teleport

Fig. 3. Screenshot of how spells can be customized in Spellcasters by clinicians using scale and depth.

Fig. 4. On the left, a screenshot of the spellbook with goal progress, and to the right, the contextual support of the non-player fairy character, subtitles, and a video pop-up demonstrating the mechanic.

to the desired location and then cast the spell. For patients who do not wish to use the teleportation mechanic, some spells summon the various creatures they can interact with, so *Spellcasters* can be experienced completely from one location. Before participatory work with stroke survivors, some preliminary spells include summoning plants and trees to decorate the garden, animal summoning spells, spells to feed animals, and animal interaction spells such as a ball to play fetch with the dog. A new spell is required for every interaction to encourage players to repeat the therapeutic motions. Figure 6 shows some of the current possible spell outcomes and the reward system's confetti particle effects when a complete set of clinician-set repetitions is completed.

The spellbook keeps track of whether the patient has completed a gesture successfully or not. When a sphere is skipped or not connected correctly, the attempt will be recorded as an incomplete attempt. If the patient is not moving for a while, the game plays a sound to inform the player that the spell is timed out, the traced line turns red, the controller provides haptic feedback, and the attempt is logged as incomplete. However, the game allows the patient to continue tracing after hearing the "incomplete" sound effect. In such a case, if the patient connects the spheres in the correct sequence, it will be recorded as a successful attempt.

Fig. 5. Screenshot of Spellcasters, stroke survivors perform exercises by tracing magical spells in a virtual environment.

Fig. 6. Screenshot of rewards in Spellcasters that clinicians can assign for each spell for stroke survivors, who will get confetti and fireworks on completion of a set of exercises.

4.3 Isolated Movement Therapy

Strokes often co-occur with hemiparesis, affecting one side of the body [11], so providing the option to play the game with either hand is essential. Stroke survivors may first play with their stronger arms when initially learning the mechanics. The spellbook has a swap hand button to quickly move the wand to either side without swapping game controllers.

As discussed in Section 4.1 some spells, such as the wrist rotations, should be performed without moving the shoulder or elbow, so we include a feature in the companion app (Described in Section 4.5) that allows medical professionals to pre-record messages and instructions that will remind patients to isolate their movements or remind them not to use a compensation strategy.

4.4 Levels

Spellcasters provides two different tutorials: One for the medical professionals and one for the stroke survivors. The tutorial for the medical professionals provides a walk-through of creating a custom spell gesture and the gesture tracing mechanic that the stroke survivors will use. The gesture tracing walk-through is beneficial for medical professionals because it allows them to test their spells and ensure they are appropriate for individual stroke survivors. *Spellcasters* are designed with multi-sensory feedback (including haptics) to be more accessible to stroke survivors who may have co-occurring disabilities such as vision or hearing impairments. The built-in non-playing character, the fairy, uses closed-captioned dialog to support accessibility. The soundscape is highly customizable, so players can independently adjust the dialog, background music, audio cues, and sound effects. The accessibility features were iterated throughout the playtesting process. For example, the pop-up video tutorials demonstrating the various mechanics were introduced after our ninth participant.

Beyond both tutorials, there are two sandbox levels: One that allows players to maintain a forest garden and one with animals that the player can interact with. The rationale behind separating the levels is to provide one experience with less sensory overload. The second level allows the player to feed animals, play, fetch, call the animals, and pet the animals.

4.5 Companion App

As the playtests and co-design sessions progressed, it became clear that it would not be convenient for medical professionals to access logs, reports, and patient management tasks within

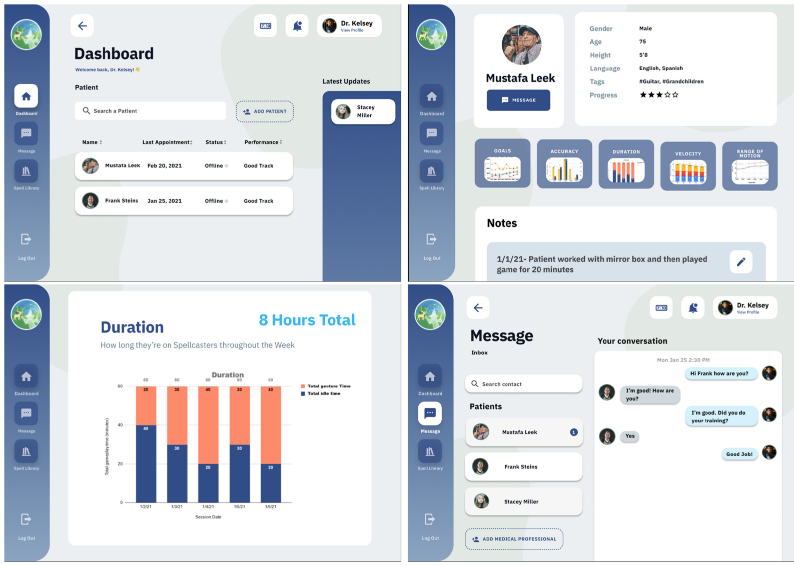
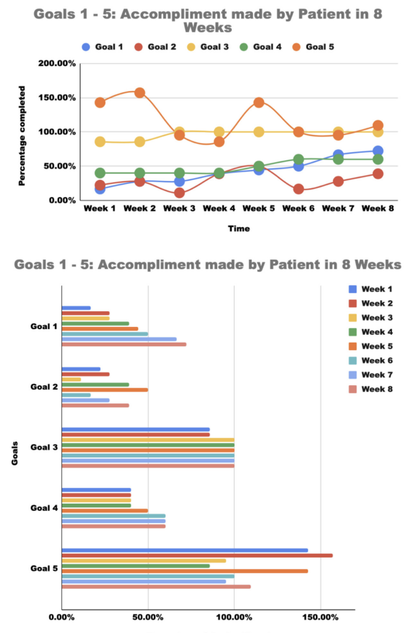


Fig. 7. Screenshots of companion web app prototype.

VR due to the (lack of) affordances for text entry. Additionally, a busy medical professional is less likely to wear a headset for quick adjustments than logging into a web app. Therefore, we rapidly iterated on the design of a companion web app using Figma for medical professionals to remotely control the game client, see data visualizations, generate reports, share resources with other medical professionals, and manage patients. The first Figma prototype can be found at this link: https://tinyurl.com/SpellcastersCompanionLowFi. The final version can be seen at this link: https://tinyurl.com/SpellcastersCompanionHighFi and is shown in Figure 7. To facilitate rapid iterations of the companion app, we used dummy data to populate the prototype. Based on how clinicians guide us on what graphs are shown and how they are formatted, we can update Spellcasters to provide appropriate data to replace the dummy data in the deployed product.

We worked closely with participants to make intuitive data visualizations. These visualizations track variables such as accuracy, velocity, time spent in-game doing exercises compared to time spent doing other activities, and range of motion. These visualizations and the overall design of the prototype were updated between each participant using a cascading iterative protocol. We provided two versions of the same visual in many iterations—the original and the updated one based on the previous participant's feedback—and asked the new participant to choose between them. The updated visualization was always chosen. The trickiest visualization we finalized was the goal tracking graph. The goal tracking graph represents goals that are both set in the game and external stroke rehabilitation goals. For example, an in-game goal might be to achieve a certain accuracy percentage or number of repetitions, while an external goal might be to walk a certain number of steps or cook a certain number of meals—all goals must be quantifiable to graph. Our original goal visualization was a spider graph, but many participants had never seen one or did not find them intuitive. In the end, we included a primary multi-line graph that provides an overview of how close each goal was met week-by-week as well a stacked line graph that breaks down each goal and a table with raw data, shown in Figure 8.

Clinicians can also write notes and set reactions to inform and motivate patients. Clinicians have access to various spells created by themselves or other clinicians, helping them reduce the need to create them frequently. They can assign these to their patients along with repetition counts.



Raw

	Goal 1	Goal 2	Goal 3	Goal 4	Goal 5
Week 1	3	4	6	4	30,000
Week 2	5	5	6	4	33,000
Week 3	5	2	7	4	20,000
Week 4	7	7	7	4	18,000
Week 5	8	9	7	5	30,000
Week 6	9	3	7	6	21,000
Week 7	12	5	7	6	20,000
Week 8	13	7	7	6	23,000
Goal	**18**	**18**	**7**	**10**	**21,000**
Average	7.75	5.25	6.75	4.875	24,375
Goal Completion	43.06%	29.17%	96.43%	48.75%	116.07%

Fig. 8. Example Goal visualizations in Companion Web app.

4.6 Usage and Setting

While *Spellcasters* takes place in a VR environment that provides an immersive experience for stroke survivors to practice depth-sensitive gestures, a concerning drawback of VR HMDs is that they wrap around our eyes, inhibiting users from seeing the real-world. To reduce the chances of experiencing motion sickness and increased safety, stroke survivors can play while sitting in a chair, and the game's teleportation mechanic is not required to play. For example, we created spells that call distant animals to the player's location. However, we have also enabled teleportation in the game so players can move around in the world if they wish, without needing to leave their chairs or get motion sick. Stroke survivors can also play while standing in one location—the gesture system will adjust to their standing height. Given the immersive nature of VR, clinicians have confirmed their interest, during our interviews with them, in using *Spellcasters* primarily in a supervised environment such as a rehabilitation facility. Once stroke survivors have made enough progress, defined and measured by their clinician, they can use *Spellcasters* as an at-home rehabilitation tool, possibly under the supervision of a caretaker, which we discuss in Section 5.3.

Another design consideration for choosing VR is the hardware cost and the prevalence of availability in rehabilitation clinics and homes. While VR is expensive hardware, the cost of consumer devices is continually becoming more affordable. For example, at the time of writing this, the Oculus Quest 2 is a standalone headset that supports hand tracking [81] and is powerful enough to run Spellcasters—available for $299. The headset does not require an expensive VR-ready computer, does not need complicated tracking towers, and is a standalone, ready-to-use device. The hand tracking features that are becoming available are valuable alternatives for stroke survivors who cannot hold a controller or do not have the dexterity to use the buttons due to the higher **System Usability Scale** (**SUS**) of hand tracking [81]. We argue that the cost of these devices is a worthy investment in an expensive healthcare climate.

5 RESULTS

For each of the 14 cascading iterative Research through Design [36, 88] sessions, we began with a semi-structured interview, followed by a playtest, and then a semi-structured design debrief to get feedback and iterate. Summaries of all the responses and transcriptions are included in the https://tinyurl.com/Spellcasters-Supplementary. We share qualitative quotes from these sessions in the relevant sections below as they relate to our research questions. The follow-up survey responses are also available in the supplementary materials, and the outcomes are presented in the following sections, organized by their related research questions.

5.1 Spellcasters (*RQ1*)

Throughout the iterative process, *Spellcasters* was updated to include recommendations made by medical professionals, including adding arrows to the gestures to make the direction of tracing clear, the inclusion of larger shapes for a range of motion exercises, and inclusion of small shapes for wrist exercises. While some clinicians prefer more presets to save their time, all clinicians found the custom gesture creation useful, as can be seen in Figure 9. Clinicians were excited about the ability to add depth to the gestures, citing its usefulness in many different exercise contexts: "I feel like you got everything covered—crossing the midline, shoulder rotations, extensions, etc." (P11), "I think it is complete—I do not have anything else that I would want to customize" (P10), and "Yeah, I think that is fantastic because you can do as small and as big as you want to make the patient do." (P6). Clinicians found the game format appropriate: "I think there is a lot that can be done with it. I think my patients are going to want to try it" (P6), "I think people would like to have this in their toolbelt to make therapy more exciting" (P3), and "It is like playing a game—they would get excited" (P13). P1 suggested we make the game support multiplayer. In terms of usability and accessibility, P6, P8, P10, P12, and P14 are concerned with some stroke survivor's ability to hold the controller or press the trigger button, which is why we will use the hand tracking feature in the Quest 2 for future testing with stroke survivors. P11 said, "I love the affirmations that you added. I like the fireworks and confetti. I think the spellbook looks good—I feel like it is readable and I can understand what is going on", and P14 suggested numbering the spheres. All 14 medical professionals mentioned Spellcasters is a potentially valuable tool for other populations, including pediatric populations and those with spinal cord injury.

5.2 Companion App (*RQ2*)

As sessions progressed, it became clear that an external tool would be helpful to clinicians to manage their patients and track their progress. The development of the companion app was prompted by P8, who said, "We only have 45 minutes with the patient, so we cannot really spend 15 minutes creating the exercises—have more presets, and a save feature so we can reuse exercises". All but 1 clinician who interacted with the companion app stated they would be interested in adopting it into their practice, shown in Figure 10. Our initial low and high-fidelity prototypes can be found in the supplementary materials, which illustrate rapid iterations and improvement based on clinician feedback. In the end, all clinicians found the visualizations appropriate, which can be seen in Figure 10. Beyond the visualizations, a reoccurring theme was that fast, easy-to-digest facts were

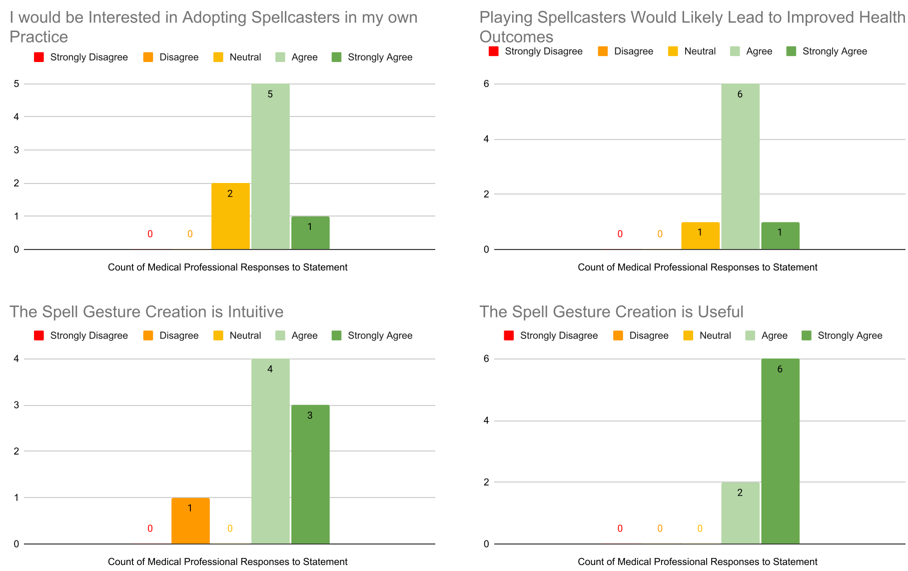


Fig. 9. Results related to *RQ1* including exercises that should be supported, interest in adopting *Spellcasters*, the likelihood of the game leading to improved health outcomes, intuitiveness, and usefulness of the gesture creation system using 5-point Likert scales of degree on the agreement to statements.

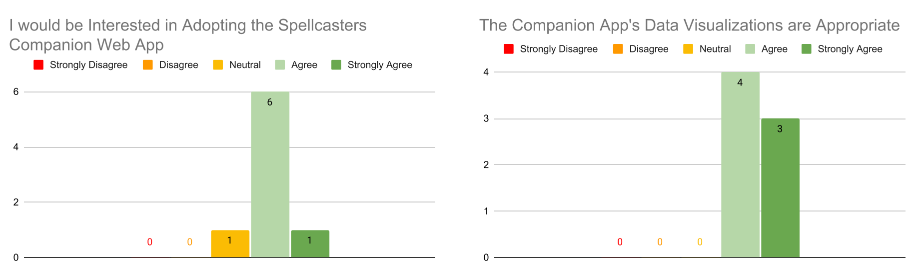


Fig. 10. Results related to *RQ2* including interest in adopting the companion web app and its data visualizations using 5-point Likert scales of degree on the agreement to statements.

preferred (e.g., P14 said, "I cannot spend much time looking at graphs, so a quick stats interface would be better"). There were many iterations on the mock data visualizations, such as for P11, who had never seen a spider/radar chart before, so we changed it to a grouped bar graph, which was clear to the following participants. Bar graphs were, by far, the preferred format.

5.3 Telehealth (*RQ3*)

Telehealth has become an even more critical part of our healthcare system today due to COVID-19. Based on our conversation with clinicians, we have found that none of them have used any telehealth games or applications beyond video conferencing tools and assigned videos (P4) due to a lack of options. The software clinicians mentioned they currently use includes *Bluestream* (3 mentions), *Zoom* (1 mention), and *Doxy.me* (1 mention). Clinicians typically use this software to watch their patients remotely on a screen and provide them with instructions. Observation through a screen is problematic because "It is much harder to get people to do telehealth with its current

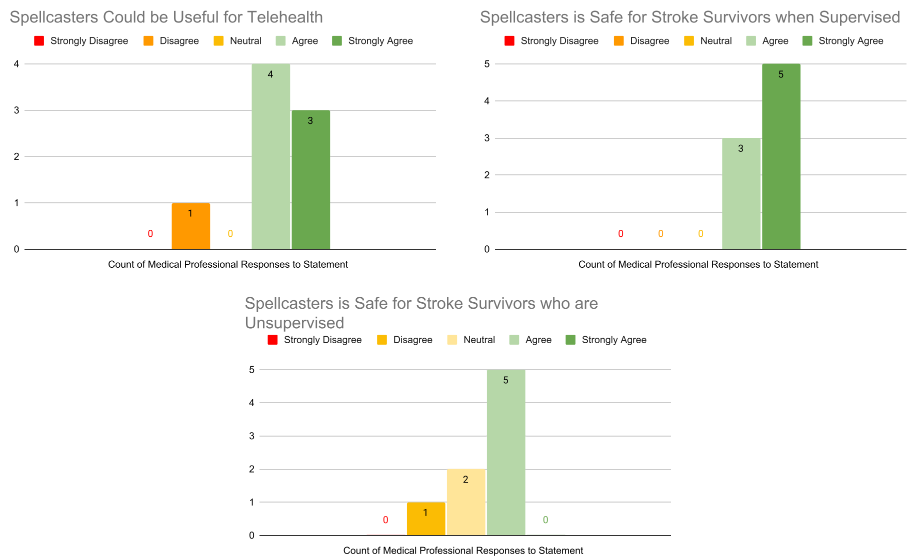


Fig. 11. Results related to *RQ3* including usefulness as a telehealth solution and the safety of using the game while supervised vs. unsupervised using 5-point Likert scales on the degree of agreement to statements.

technology—they need many other cues than the limited visual and audio cues we have now" (P3). Because of the limited set of activities they can do while remote, clinicians have suggested that patients have been eager to go back to their traditional in-person system. 4 clinicians have never done telehealth and continued to offer in-person care during the COVID-19 pandemic. P8 serves many patients from a lower socioeconomic status and is concerned with telehealth because of their limited access to good digital resources. These conversations confirmed our agreement with our institutional ethical review board—we need to wait to work with stroke survivors until after the vaccine is widely administered or after teleconference tools are made more accessible.

Spellcasters have the potential to serve as a telehealth option as access to VR becomes more common—and clinicians tend to agree that *Spellcasters* could be useful in this context (shown in Figure 11). P5 indicated that "If *Spellcasters* can help them stay more consistent with their program, then sure—really consistency is the name of the game, so anything that can help somebody be more consistent is going to be a win." P3 said, "I believe that if you can tie it to patient adherence, then you can correlate that to improvement—and that goes to taking it at home with you and doing it more often." Safety was one of our primary concerns because, in the home context, stroke survivors may be practicing without a present medical professional, but as can be seen in Figure 11, medical professionals tend to believe the game would be safe (more so with supervision). Many indicated this is due to the ability to play the entire game while seated.

6 DISCUSSION

In this section, we begin by discussing our autoethnographic insights [26] about converting *Spellcasters* from a pure entertainment game into a serious game for health for stroke rehabilitation. Next, we present our interpretations on the three research questions that drove our Research Through Design iterative process [36, 88]. Namely, the importance of being able to customize therapy mechanics for the personal needs of stroke rehabilitation, the potential benefits of using game telemetry to inform scalable and equitable data-driven healthcare solutions, and games as an option for future telehealth opportunities, which is particularly relevant in the wake of COVID-19. Finally, we discuss the limitations and future directions of our work.

6.1 Converting Entertainment Games to Therapy Games

At the project's onset, we were hopeful that converting an entertainment game into a serious game for health would reduce development time and offer some promise for translating mechanics already proven to be fun and engaging. We ultimately redeveloped the game from the ground up and drastically altered many original core features, including the multiplayer magical duels, and created an entirely new gesture system. Still, the time and effort were significantly reduced than if we started from scratch because the shared vision was clear from the onset. However, these changes come with some inherent risk: the original qualities that made the original Spellcasters fun could be lost in translation. Some of the old features, namely the multiplayer competitive experience, may come back based on future design work with stroke survivors (or they might lead us down an entirely different path). Because *Spellcasters* is an open sandbox world, we now have an opportunity to co-design with stroke survivors using the simple spell-casting mechanic to afford a multiplicity of design directions—from a narrative adventure to multiplayer duels to tending magical gardens. Most of our investment, and the main novel contribution of this work, is the intuitive custom rehabilitative gesture creation system paired with a companion app, which could be extended to support many different domains other than a magical world if stroke survivors show interest during future participatory design sessions. To provide this essential resource to stroke survivors as quickly as possible with the restraints of the pandemic, we chose to draw inspiration from an existing entertainment game rather than use Participatory Design with stroke survivors. While the gold standard would have been to enlist stroke survivors as co-designers at the onset, the COVID-19 pandemic restricted our options, so we chose to investigate this higher research question of whether there is value in repurposing existing entertainment games into therapy games. While this work can not thoroughly answer this more meta-level question, our experience so far has been that the shared vision and available resources (existing source code, design documents, aesthetic style, existing mechanics) made our development much more time-efficient than exploring many possibilities spaces. Our results from clinicians are promising in that they believe stroke survivors will love the magical world and spell-casting domain.

6.2 Custom Therapy (*RQ1*)

Healthcare does not follow a "one shoe fits all" model—everyone has individual goals, needs, abilities, and preferences [33]. Stroke medical professionals employ numerous strategies for motivating their patients based on their patient's health, environmental factors, and personal factors [61]. The primary mechanic in *Spellcasters* is making gestures to cast spells—and one of our primary contributions in this work is designing an intuitive gesture creation system that medical professionals can use to customize *Spellcasters* for their patients. From the feedback we collected, this is by far the most valuable feature in the game (Section 5.1). The gesture creation system is also where most of the development effort went. We prioritized this mechanic because we believe the core mechanic in a serious game for health is central to the success of the game—it should be accessible, customizable, lead to improved health outcomes, intuitive, engaging, and data-driven—a tall order. We plan to work with stroke survivors in the future to ensure it is genuinely accessible, intuitive, and engaging.

6.2.1 Future Work. As discussed in Section 3.4, *Spellcasters* currently follows an overly clinical model because we have not yet incorporated input from stroke survivors. We have made *Spellcasters* customizable from the perspective of clinicians (which is very important), but therapy should also be customizable from the players' perspective. A research question that will drive our future work is: *How can Spellcasters holistically support stroke survivors?*

6.3 Companion App (*RQ2*)

Companion apps create added value towards long-term engagement in games for health because they can visualize progress and medical information, increase the perceived value of compliance with sustained use, and can help embed the training routine in daily practice [43]. As the iterative design process progressed with *Spellcasters*, it became clear that medical professionals were interested in quantitative insights and data visualizations from the game but did not think it would be convenient to wear a headset and launch the game to access them. Additionally, the affordance of VR is not as suitable for patient management as traditional web browsers. Once we introduced the companion app Figma prototype, medical professionals were highly enthusiastic (Section 5.2). Instead of focusing on the app's actual implementation details, we were primarily focused on designing the data visualizations, information organization, intuitive navigation, and desired features the companion app would support—Figma was highly effective because we could rapidly iterate between each session.

6.3.1 Future Work. Medical professionals were highly interested in community-based sharing of sets of spell gestures and communication with their patients within the game. We think the social affordances of a companion app for serious games for health are highly interesting. A 2-part research question that will drive our future work is: *How do social affordances in the Spellcasters Companion app affect the gameplay experience and relationship between stroke survivors and their clinicians*. We plan to study the impact of the companion app on the gameplay experience and relationships with clinicians by conducting a comparative study where one group of stroke survivors has access to the companion app while another does not. Each group would take a player experience inventory [2] and an inventory of the clinician-patient relationship [41] for comparison.

A benefit to using serious games for health is the added ability to collect rich data using game telemetry [22]. This data can train machine learning models to better support players by predicting when they need support, more accurately sensing their therapy-based mechanics, and standardized metrics for developing a therapy curriculum. We are interested in exploring how machine learning can support stroke survivors who play *Spellcasters*. A research question that will drive our future work is: *How can machine learning support stroke survivors who play Spellcasters*.

6.4 Telehealth (*RQ3*)

Many medical professionals are becoming experts at meeting with their patients remotely—our first participant, without prompt, said he needed to optimize his screen share in Zoom for videos, indicating that he was well-versed with the software's advanced features. While telehealth has been around for almost 50 years [9], the COVID-19 pandemic has created an explosion of the need for more telehealth options [56]. Most medical practitioners felt *Spellcasters* would be useful and safe in a clinical setting because the stroke survivor would be supervised (Section 5.3). However, a few of the participants indicated that they are hesitant to recommend *Spellcasters* for at-home use while unsupervised. If a stroke survivor injured themself, there might not be anyone around to respond. It helps that *Spellcasters* can be played while seated, but more work remains into investigating how safe VR is for unsupervised stroke survivors (and if the game will require a supervisor).

6.4.1 Future Work. Based on our literature review (Section 2), we believe that telehealth options will remain an integral element of healthcare even beyond the COVID-19 pandemic and that *Spellcasters* has many qualities towards becoming a telehealth solution. We plan to continue designing *Spellcasters* with stroke survivors. After the game is complete, a research question that we will investigate is: *Is Spellcasters safe for at-home stroke rehabilitation?* Whether or not *Spellcasters* is played primarily in clinics or at home, we plan to conduct a longitudinal study to evaluate the efficacy of the game for improving rehabilitation outcomes.

6.5 Limitations

COVID-19 directly influenced our procedures for co-designing and evaluating *Spellcasters*, adding limitations to our work. The three primary limitations of our work are the exclusion of stroke survivors, the limitations of running a remote protocol with varying access to VR systems, and aggregating evaluations of a design that was constantly being iterated on and changing. Until the vaccine for COVID-19 is widely distributed, our institutional ethics review board and we agree that it would be unsafe to include stroke survivors as participants in the research both in-person and remotely (due to accessibility concerns). We worked exclusively with medical professionals for this contribution as a precursor to participatory work with stroke survivors when it is safe to meet in person again. Ideally, each of our participants would have experienced *Spellcasters* in VR, but only 3 of our participants had access to the hardware. We did not ship VR systems with *Spellcasters* installed to each participant due to resource constraints, logistics of shipping back and forth, and the risk of transmitting the COVID-19 virus. While it was not ideal, the remote sessions where we demonstrated the game by screen-sharing were still productive and led to valuable insights. The nature of Research through Design [36, 88] is iterative and results in a continually-changing intervention as feedback is incorporated into the game and companion app. Therefore, when we asked participants to evaluate the design, they saw a different version of the design than the next participant, limiting the reliability of aggregated results. The post-survey included a trailer with the updated design of the game and a link to the companion app so participants could see the final design. Our results were generally positive, and we believe they offer some value for presenting our contributions.

6.6 Affordances of Virtual Reality

One of the limitations of iVR is that current sensing abilities limit physical rehabilitation to the upper limbs. However, some available trackers can be attached to more body locations [1, 77] for more accurate and thorough tracking. We chose not to use them because of the additional costs, accessibility concerns, and pragmatic constraints of conducting a remote protocol. New commercial iVR hardware is beginning to support more lower-extremity tracking using the headset, and we are interested in exploring using this with *Spellcasters* in the future when the technology is widely available. Right now, *Spellcasters* can run on Oculus Rift, Quest (with link cable), and HTC Vive. Each of these devices needs to be connected to a Windows computer to operate. We are interested in eliminating this barrier by porting the game to wireless VR headsets to make Spellcasters more accessible and cheaper to adopt.

7 CONCLUSION

In this article, we present the design of a novel serious game for health and a companion app for stroke rehabilitation, called *Spellcasters*. We provide an autoethnographic reflection of converting a game originally designed for entertainment into a therapy game. We share results from co-designing and evaluating our software with 14 medical professionals using remote Research through Design protocol. We found that the ability to customize the primary (therapy) mechanic was the most valuable game feature to support therapy. We share the design of the *Spellcasters* companion app that is rich with tacit design knowledge about the types of data visualizations that would be useful to medical professionals and how they should be intuitively communicated. We describe the implications of our software towards a potential telehealth solution for stroke rehabilitation, including patient management and community-based sharing of spells. The contributions of this work include novel artifacts, insights into designing serious games for health, and implications for scalable and equitable telehealth solutions.

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Subject-matter experts: Michaela Sandock, Carter Mcelory, Michael John, Magy Seif El-Nasr, Elin Carstensdottir, Katelyn Grasse, Joaquin Anguera, Pedro Cori.

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