Rehabilitation Games in Real-World Clinical Settings: Practices, Challenges, and Opportunities

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Upper-limb impairments due to stroke can severely affect the quality of life in patients. Scientific evidence supports that repetitive rehabilitation exercises can improve motor ability in stroke patients. Rehabilitation games gained tremendous interest among researchers and clinicians because of their potential to make the seemingly mundane, enduring rehabilitation therapies more engaging. However, routine and longitudinal use of rehabilitation games in real-world clinical settings has not been investigated in depth. Particularly, we know little about current practices, challenges, and their potential impacts on therapeutic outcomes. To address this gap, we established a partnership with a rehabilitation hospital where game-assisted rehabilitation was routinely employed over a 2-year period. We then conducted an observational study, in which we observed 11 game-assisted therapy sessions and interviewed 15 therapists who moderated the therapy. Significant findings include (1) different engagement patterns of stroke patients in game-assisted therapy, (2) imperative roles of therapists in moderating games and challenges that therapists face during game-assisted therapy, and (3) lack of support for therapists in delivering patient-centered, personalized therapy to individual stroke patients. Furthermore, we discuss design implications for more effective rehabilitation game therapies that take into consideration both patients and therapists and their specific needs.

CCS Concepts: • Human-centered computing → Empirical studies in HCI; • Applied computing → Health care information systems;

Additional Key Words and Phrases: Serious games, neofect rapael smart board, post-stroke patients, rehabilitation, upper-limb motor rehabilitation

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1 INTRODUCTION

Upper-limb impairments due to stroke cause weakness, diminished dexterity, and limited ability to perform reaching and grasping movements [137], thereby affecting stroke survivors’ performance of essential Activities of Daily Living (ADLs) and leading to significantly lower health-related quality of life [34, 45]. There exists robust scientific evidence supporting that repetitive, high-dosage rehabilitation exercises performed in a therapeutically appropriate, quality manner could improve motor abilities of patients1 [64, 120, 121, 132] as a result of motor learning processes (i.e., neuroplasticity) [15, 21]. However, it is challenging for patients to stay engaged in seemingly mundane, repetitive exercise movements and, at the same time, maintain their attention on the quality of their movement execution (e.g., speed, accuracy, smoothness, and postures), both of which are essential in maximizing therapeutic outcomes [73]. In turn, low motivation in stroke patients and their poor engagement in therapy serve as a major barrier that hinders their potential functional recovery [112].

A number of studies have investigated the use of serious games to improve therapeutic gain through enhanced patients’ motivation and engagement level during rehabilitation therapy. Clinical research communities have attempted to validate the therapeutic effectiveness of Commercial Off-The-Shelf (COTS) games (e.g., Nintendo Wii or Sony PlayStation) in upper-limb rehabilitation [119, 135]. Although more rigorous clinical evidence is necessary to conclude the effectiveness of COTS games in rehabilitation therapy [119, 135], some clinical studies suggest that serious games may improve the rate of recovery in patients’ motor function [88, 125]. On the other hand, a review paper by Lohse et al. suggest that the motivation level enhanced by the use of games vary among patients, which may lead to different therapeutic outcomes [83], but no in-depth discussions were provided. In another study by Brütsch et al., authors quantitatively show that therapists’ active involvement in the game-assisted therapy (e.g., providing additional feedback for patients’ performance) may significantly improve the clinical outcomes [20]. Similarly, in conventional rehabilitation, it has been widely accepted that patients’ engagement and adherence level may vary [26, 65, 98] and that therapists play significant roles in maintaining patients’ engagement and ensuring the quality of performed exercise movements [140, 144]. While there has been some speculation about the roles of therapists in moderating game-assisted therapy sessions and suggestions around different engagement levels in patients, there have been no studies that investigated these matters in depth.

As of now, the majority of studies in human–computer interaction communities stop short at investigating the usability of rehabilitation games [2, 3, 9] only after deploying the system to patients and clinicians for a relatively short period of time (e.g., a few days). There exists only a handful of observational studies that particularly focused on game-assisted stroke rehabilitation therapy in real-world clinical settings after long-term deployment of the games [106]. This causes an inevitable gap between the reality and our understanding of stroke patients’ heterogeneous engagement patterns, therapists’ roles, interaction dynamics between patients and therapists, and practical challenges they encounter. More importantly, such a gap hinders us from analyzing the actual therapeutic impacts of game-assisted stroke rehabilitation. To systematically comprehend the dynamics among patients, therapists, and games—thereby, the resulting therapeutic effectiveness—it is critical to investigate game-assisted rehabilitation therapy in real-world settings, where such interventions are routinely employed on a daily basis [9, 13].

1 Stroke survivor is the conventionally accepted term in the clinical literature to represent those individuals who survived from a stroke in any recovery stage (e.g., acute, sub-acute, and chronic). However, because therapists generically referred the stroke survivors that they were treating as patients in the collected data, we used both terms interchangeably in this work.
Our research goal in this study is to achieve a deeper understanding of the real-world interaction dynamics between patients, therapists, and games, and the associated challenges in enabling game-assisted rehabilitation therapy. Our primary research questions are threefold: (1) How do patients engage in game-assisted therapy in real-world clinical settings? How does the gamification of rehabilitation exercises affect patients’ engagement in therapy and thereby, therapeutic outcomes? (2) What are the roles of therapists during routine game-assisted therapy sessions, while the rehabilitation game tools and systems automate some part of therapists’ conventional roles in non-game-assisted therapy? and (3) Are there any practical challenges that therapists encounter when practicing those roles? Towards that end, we conducted a single-site study at a rehabilitation hospital in South Korea, where serious games were used as part of its routine stroke rehabilitation program. We first video-recorded 11 one-on-one therapy sessions between therapists and patients, spanning a total of 5.5 hours of observation, which employed a commercially available serious game system that is specifically designed for stroke upper-limb rehabilitation (see Section 3.4 for details). Then, we conducted semi-structured interviews with 15 therapists, aiming to obtain in-depth knowledge related to motivation, implication, and consequences of the interaction dynamics that we initially observed in the video recordings. To understand the dynamics that are well-established after long-term exposure to game-assisted therapy, we recruited patients who had received 30-minute-long game-assisted therapy sessions 5 times a week for at least 1 month and therapists who had at least 3 months of daily experience moderating game-assisted therapy, at the time of recruitment. The video-recorded therapy sessions and audio-recorded interviews were analyzed using Thematic Analysis [18]. Our key findings in this study include identifying (1) four different types of interesting engagement patterns in patients and the resulting interaction dynamics with therapists and the game system, (2) therapists’ comprehensive and orchestrating roles in maintaining patients’ engagement and therapeutic values, and (3) the lack of hardware and software support for therapists to enable patient-centered, personalized therapy. More specifically, some notable findings include conflicts between therapists and patients who are overly engaged in the entertainment aspect of game-assisted rehabilitation therapy, active involvement of therapists as a leading user of the game system, the importance of the game system’s customizability for therapists to support patient-centered interventions, and the importance of training for therapists to effectively moderate game-assisted therapy. Building on these findings, we offer promising design implications for rehabilitation games, such that therapists can better administer game-assisted therapy programs and maximize therapeutic outcomes.

2 RELATED WORK

2.1 The Use of Games in Stroke Rehabilitation and Its Challenges

Research and clinical communities have considered games as an effective means to enhance patients’ motivation, engagement, and adherence to seemingly repetitive and banal task-oriented therapy (e.g., repetitions of reaching and/or grasping movements) [67, 113]. As a result, a large volume of studies have focused on investigating the clinical effectiveness of COTS games in upper-limb rehabilitation for stroke patients (e.g., flexion and extension of the affected shoulder, elbow, and wrists, and ab/adduction of the affected shoulder). Some studies suggest that game-assisted therapy using COTS games can yield motor recovery in stroke patients. For instance, Yavuzer et al. reported that stroke survivors who received 18 half-hour sessions of game-assisted therapy using the PlayStation II EyeToy achieved statistically significant improvement in the performance of ADLs [147]. Choi et al. found a significant improvement in stroke patients’ upper-limb motor function after practicing 20 half-hour sessions of game-assisted therapy using the Nintendo Wii [23]. According to Lee, patients improved their muscle strength and ability to perform ADLs after...
18 1-hour-long sessions of game-assisted therapy, each of which consisted of a 30-minute XBox Kinect game play session and a 30-minute conventional therapy session [77]. In addition, a few studies suggest that game-assisted rehabilitation therapy or game-assisted therapy in conjunction with conventional rehabilitation therapy may lead to a greater recovery rate when compared to conventional therapy alone. For instance, Manlapaz et al. reported that, after 12 half-hour therapy sessions, patients who received Nintendo Wii-based therapy achieved greater improvement in their motor function and spasticity (i.e., resistance to muscle stretching and a common motor symptom in stroke patients) compared to those who received conventional physical therapy [88]. Finally, Sin et al. showed that patients who practiced a combination of XBox Kinect-based therapy and conventional occupational therapy achieved a greater improvement in motor function and range of motion when compared to those who only received conventional occupational therapy [125].

While the primary research goals of the above-mentioned prior work were on validating the clinical effectiveness of serious games in rehabilitation, a few studies have briefly discussed the usability issues that stroke patients experience with the game systems (all of which were COTS systems). Rand et al. suggested that COTS games could be cognitively and physically too difficult for some patients to self-administer because the games and their interfaces are developed for the purpose of entertainment in the non-disabled, healthy population [114]. Alankus et al. found that patients with significant fine-motor impairments were not able to continuously hold the Nintendo Wii controllers and needed to affix the controllers to their hands using a strap [3]. Similarly, Lange et al. stated that 8 out of 20 stroke survivor participants were not able to complete the initial calibration process that Xbox Kinect used to customize its skeletal tracking model to participants’ different body configurations, and the remaining 12 patients managed to complete the process only with therapists’ assistance [75]. Consequently, the above-mentioned issues with the user interfaces of COTS games might hinder the effortless game play of stroke patients, which in turn could hurt their motivation in game-assisted therapy.

A number of prior studies have attempted to overcome these limitations of COTS games by proposing different types of controllers to accommodate varying levels of patients’ motor impairments and their specific therapeutic needs. For instance, Wang et al. proposed a board with LED-powered buttons that patients could interact with by using only gross-arm movements for those with limited fine-hand motor skills [142]. On the other hand, Morrow et al. developed a sensor-instrumented glove controller for XBox that could monitor finger movements for stroke survivors who specifically need to rehabilitate their fine-hand motor skills [93]. Sugar and Dyar [50] introduced virtual reality systems that can provide a customized means for patients to interact with the system depending on their impairment level while practicing real-world ADLs related to patients’ specific needs. However, these studies do not provide a systematic analysis of patients’ engagement patterns and motivation levels when they were exposed to their interactive techniques.

The existing literature on serious games for rehabilitation, nevertheless, collectively hint for potential heterogeneity in the engagement patterns of stroke patients depending on their cognitive and impairment condition [3, 75, 114]. Due partially to this, Lohse et al. suggested that game-induced patients’ motivation and engagement may vary depending on patients’ impairment level, and the involvement of therapists might be necessary in game-assisted therapy [83]. Since motivation is considered one of the most important factors that could affect the clinical outcomes of rehabilitation therapy [85], variations in the game-induced motivation pattern may affect the outcomes in real-world clinical settings. To the best of our knowledge, there exist no studies to date that have systematically and conjointly investigated the interaction dynamics among patients, therapists, and games, which calls for more in-depth research endeavors.

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2.2 Lack of Understanding of Therapists’ Roles in Game-Based Stroke Rehabilitation

Indeed, clinical studies suggest that patients’ cognitive and motor impairments can affect their performance of exercise movements in conventional therapy. Cognitive impairments affect patients’ abilities to process external stimuli, pay attention, and self-monitor their own movements [26, 65, 98]. Motor impairments hinder the execution of therapeutically appropriate movements and, consequently, patients often develop task-specific compensatory behaviors using their less-affected body parts (e.g., lifting their shoulders to raise their hand or leaning their trunk forward to reach out to grab an object) [80]. These behaviors are clinically important because they may lead to a phenomenon referred to as learned non-use (i.e., patients learn to cease using their affected limb) [72, 131], which significantly hampers brain plasticity, the key to maximizing functional recovery throughout the rehabilitation process [78, 80]. In conventional rehabilitation settings, it is therapists’ responsibility to design therapeutic activities and adjust their difficulty levels to best accommodate patients’ different impairment conditions [44, 94, 116], and to provide verbal and physical feedback to maintain patients’ engagement as well as the quality of patients’ exercise movements [140, 144].

Although some previous studies have hinted the necessity of therapists’ involvement in game-assisted therapy [75, 83], there have been no prior studies that specifically investigated therapists’ active roles in serious game-based rehabilitation therapy. This is partially due to a belief that serious games can—to some extent—automate part of therapists’ roles. For instance, a study by Balaam et al. on the development of a personalized gaming system for patients with different impairment types and severity levels briefly reported that therapists’ involvement was necessary to assemble different gaming components to accommodate patients’ specific needs and enable personalized therapy [9]. Alankus et al. attempted to develop rehabilitation games that could enhance patients’ compliance with the regimen. The authors mentioned that therapists were substantially involved in designing therapy sessions by selecting the type of games to play and the associated difficulty level in order to accommodate heterogeneous impairment conditions and the recovery pace of different patients [3]. Similarly, Joo et al. hinted that occupational therapists were needed to determine games that were suitable for individual patients and to personalize the game equipment (e.g., affixing Nintendo Wii remote controllers to patients’ hands using straps) [56]. Deutsch et al. briefly suggested that feedback produced during Nintendo Wii games may not be sufficient to ensure the quality of patients’ movements and recommended therapists’ involvement and supervision during game play [28]. The above-mentioned studies independently suggest that therapists’ involvement is much needed in game-assisted therapy to ensure therapeutic benefits. However, these studies mainly focus on either validating the therapeutic effectiveness of COTS games or improving the usability of games for stroke patients, rather than systematically analyzing therapists’ roles and practical challenges they face during game-assisted therapy and studying how serious games could be better designed to support their roles.

2.3 The Use of Game-Based Stroke Rehabilitation in Real-World Settings

Studying the dynamics of rehabilitation game play in real-world clinical settings is particularly important [14], as it can reveal complex and unexpected phenomena that cannot be otherwise observed in controlled, experimental settings [9, 13]. Despite research communities’ strong emphasis and recommendation for investigating health-care technologies “in the wild,” there exist only a few studies that have studied the use of rehabilitation games after adopting the regimen as part of the routine clinical practice for a long-term period. One notable example on stroke rehabilitation is an observational study by Pickrell et al. that was conducted in a hospital setting over a four-month period [106]. Aiming to understand effective feedback strategies to enhance patients’ motivation,
Pickrell et al. investigated game-assisted therapy sessions for exercising standing-balance using a custom-designed game [16] as well as a set of Nintendo Wii games. While the major objective of the work in [106] was to offer design guidelines for appropriate feedback to maximize patients’ motivation level, the authors also hinted that not every stroke patient enjoyed game-assisted therapy, and some patients considered that game-generated feedback was not helpful. In addition, the authors observed that therapists provided various assistance to support patients’ game play. However, patients’ engagement patterns, therapists’ roles, and challenges were out of their research scope and not discussed in depth.

There exist some observational studies that investigated game-assisted therapy in real-world settings, although targeting different user/patient populations [5, 22, 38]. Gerling et al. explored the practical challenges and opportunities of using games in long-term care facilities to motivate the elderly population for physical exercises [38]. The study focused on understanding the elderly’s experience of games and on discussing game design guidelines to integrate games into self-administered leisure activities. Annema et al. analyzed the overall procedure of game-based therapy for children with cerebral palsy and patients with multiple sclerosis to understand ways to enhance the usability of games for therapists [5]. The authors reported that therapists found it difficult to deliver therapy effectively and secure sufficient net exercise time when utilizing COTS games (e.g., Nintendo Wii) partially due to the complex configuration/calibration mechanism, unskippable cinematic animations, and lack of reports on patients’ performance. Cheng et al. sought to understand the context of using COTS games (e.g., Nintendo Wii) in a rehabilitation hospital setting with a goal to enhance the engagement of patients with brain injuries to therapeutic regimens [22]. The authors concurred with the findings by Annema et al. on the limited net practice time and briefly mentioned therapists’ roles in game-assisted therapy. However, these prior studies do not provide an in-depth discussion about different engagement patterns of patients and the underlying traits that could have affected the patterns. Furthermore, it was not discussed how such patterns change therapists’ roles and intervention strategies, and challenges that therapists face to perform their roles. Stroke can affect patients’ cognitive and motor functions in varying degrees. Such variation introduces greater complexity to patient characteristics, therapeutic goals, and interaction dynamics among patients, therapists, and games, which cannot be understood by the findings of the above-mentioned prior studies. This creates a gap in our understanding and knowledge, which highlights the need for investigating both stroke patients, therapists, and their interactions during routine game-assisted therapy in real-world clinical settings.

3 STUDY DESIGN

This study aims to achieve a better understanding of current practices and challenges that arise while therapists interact with patients and games in the actual clinical setting, where serious games are used as part of the routine rehabilitation program. Furthermore, it is our goal to offer design and research suggestions to better support patient-centered, personalized game-assisted rehabilitation therapy. This section describes our study design in detail to achieve these goals.

3.1 Study Site

We conducted our study at Heeyeon Rehabilitation Hospital (HRH) in South Korea. Our research team initiated a research partnership with HRH in June 2016 and have performed a set of research projects since then, focusing on the clinical evaluation of therapist-supervised game-assisted rehabilitation tools [58, 100]. During these studies, we observed unanticipated interaction dynamics between therapists and patients, discrepancies between the expected and actual engagement patterns of patients, and therapists’ roles in game-assisted therapy, which led to the conceptualization of this qualitative study. We strategically chose our study site due to its access to a large number
of stroke survivors with various functional and cognitive conditions, the hospital’s active adoption and utilization of state-of-the-art rehabilitation technologies including various game-assisted therapy systems, therapists’ daily exposure to such technologies, and the close relationship that our team has built with the therapists throughout a series of research collaborations. The hospital ran both a rehabilitation center and a nursing home facility. In August–September 2018, when the observational studies and interviews were conducted, approximately 700 patients were residing in the entire hospital, about 500 of whom were post-stroke patients with a variety of impairment types and severity levels. Many of these patients were in their first 2 years since the most recent stroke because the Korean national health insurance system subsidized a substantial amount of patients’ health-care costs during the first 2 years. The hospital employed over 120 full-time therapists at the time of this study, and about 60 of them were occupational therapists. As part of their work requirement, therapists had regular meetings and peer training, where they reviewed academic papers and shared their experiences related to intervention skills with each other. Hence, albeit the possibility of inter-variability in the therapy style among therapists, it was reasonable to assume that they shared common intervention strategies to some extent.

The hospital adopted and operated routine rehabilitation programs and technological solutions that were comparable to modern rehabilitation hospitals in many other countries. Game-assisted rehabilitation tools that were routinely utilized at HRH included the Rapael Smart Board (Neofect, South Korea/USA) for gross upper-limb movement rehabilitation, and the Smart Pegboard and Rapael Smart Glove (Neofect, South Korea/USA) for fine-hand movement rehabilitation. Besides the serious game technologies, therapists also regularly conducted computerized cognitive rehabilitation therapy using RehaCom (HasoMed, Germany) and robot-assisted physical therapies for upper and lower limbs using Armeo, Erigo, Lokomat, and Andago robots (Hocoma, Switzerland), which are some of the most commonly used rehabilitation technologies worldwide. Furthermore, the number and duration of upper-limb motor rehabilitation therapy sessions in HRH (i.e., 30 minutes per session and therapy for 7 days per week) were comparable to those in other developed countries (i.e., the average dosage of 36 minutes, 5 days per week in the United States and Canada [74]).

3.2 Participants

In order to understand general interaction dynamics between therapists, patients, and the game system during game-assisted therapy, we recruited pairs of an occupational therapist and a patient who had been engaged in game-assisted upper-limb therapy. The inclusion criteria stipulated that occupational therapists needed to have conducted at least 3 months of game-assisted therapy using the target rehabilitation game system (i.e., Rapael Smart Board; see Section 3.4 for details) and patients needed to be undergoing and had received the game-assisted therapy every day (i.e., seven-times a week) for at least 1 month at the point of recruitment. All study participants were recruited by word of mouth and/or study fliers that described the anticipated study procedure (see Section 3.3) and the inclusion criteria. When the potential subjects volunteered to participate in the study, research staff explained the risks/benefits associated with the study and obtained informed consent for video-recording their therapy sessions. A total of 11 pairs of occupational therapists (7 females, 25 ± 2 years old, 2 ± 1 years of practices, 9 ± 3 months of moderating game-assisted therapy; mean ± standard deviation) and stroke patients (6 females, 69 ± 12 years old, 1.3 ± 0.7 years since their latest stroke) were recruited. The patient participants had a wide range of motor function (i.e., spanning from severely impaired to highly functioning patients in terms of 49 ± 21 points in Wolf Motor Function Test [146]) and mild cognitive impairment (i.e., 23 ± 4 points in Korean Mini Mental State Examination [61]). Second, in order to further understand occupational therapists’ thoughts and lived experiences from the interactions observed in the video-recorded
sessions, we recruited 15 occupational therapists (10 females, 25 ± 2 years old, 3 ± 2 years of practices, 9 ± 3 months of moderating game-assisted therapy) for a one-on-one, audio-recorded semi-structured interview. The same inclusion criteria were applied to these therapists. A total of 11 of these 15 therapists also participated in the aforementioned video-recorded sessions. The average duration of the interviewed therapists’ experience in game-assisted therapy was also 9 months. Therapists stated that they administered approximately 1–2 game-assisted therapy sessions per day, which amounts to 270–540 sessions in the 9-month period. Therapists also estimated that they would treat approximately 10–20 different patients using game-assisted therapy in the 9-month period.

3.3 Procedure

The experimental procedure was approved by the Institutional Review Boards (IRB) of the University of Massachusetts Amherst (IRB# 2018-4850) and HRH. In order to minimize any potential discrepancies between therapists’ opinions during the interviews vs. the actual interactions observed during the routine game-assisted therapy sessions, the recruitment of participants was intentionally conducted in two sequential stages. The video-recorded therapy sessions were first analyzed to study interaction dynamics among patients, therapists, and games during game-assisted rehabilitation. Then, interview questions for therapists were subsequently prepared to investigate motivation, reason, implication, and consequences of the observed intervention strategies.

For each pair of a therapist and a patient who agreed to participate in the study, we randomly selected one game-assisted therapy session in August 2018 to video-record. We decided to video-record the therapy sessions, rather than observing in person, to minimize disrupting or influencing the usual interaction dynamics. The video camera was installed on the ceiling with a top-down view above the Rapael Smart Board to minimize the obtrusiveness of the equipment. This provided an unobscured view of the patient’s movements and physical interventions provided by the therapist. An external microphone was connected to the video camera and placed on the side of the Smart Board tablet computer so that the conversation between therapists and patients could be clearly recorded. The video-recorded therapy sessions were conducted in a room of size approximately 4 × 4 m² with a glass wall that people could see through. There was one unit of Smart Board in the room, which could serve 14 30-minute-long therapy sessions per day.

In order to gain a better understanding of current practices and challenges that were observed in the video-recorded therapy sessions, we conducted one-on-one semi-structured interviews with therapists in September 2018. Interviews lasted for 30 minutes on average, either in an empty office or in an uncrowded hallway within HRH based on the therapists’ preference. To ground the interviews on the actual representative interactions between therapists and patients, interview questions were designed based on the analysis of the entire video-recorded game-assisted therapy sessions. Therapists were asked to share their thoughts based on their overall experience with game-assisted therapy in general, not limited to the specific interactions that we observed in the videos. Furthermore, although our observations were made on the therapy sessions that employed Rapael Smart Board, the therapists were allowed to talk about their broader experience with other rehabilitation games during the interview. We asked therapists about patients’ responses towards games and therapists’ strategies for effective therapy when encountering patients’ different response patterns (e.g., In the video-recordings, we observed different attitudes in patients during game-assisted therapy. Can you tell me more about patients’ response patterns to rehabilitation games and your interventions for effective therapy?) and how it affected therapists’ intervention (e.g., How and who select games or difficulty levels to personalize games for patients? Why?). Then, we asked about the representative roles of therapists (e.g., In the video-recordings, therapists provided a substantial amount of feedback or assistance to patients during game-assisted therapy. Can you describe
Fig. 1. The RAPAEL Smart Board and the screenshots of three example games that practice different types of upper-limb movements (courtesy of Neofect Inc. [96]). (a) A demonstration of game-assisted therapy using Smart Board. (b) The pet-feeding game, in which patients need to make point-to-point two-dimensional reaching movements to move food to feed dogs and cats. (c) The dough-mixing game, in which patients need to repeat circular hand movements following a visual trajectory (i.e., to remain inside the rim of a bowl) to make bread dough. (d) The grocery-shopping game, in which patients need to move around a grocery store by reaching to arrow keys that are displayed on the bottom of the screen and collect the asked grocery items again using point-to-point reaching movements.

Can you tell me about the challenges you experienced? What do you think are the primary reasons for the challenges?). We also asked therapists about the challenges they faced (e.g., your intervention strategies more?).

3.4 Apparatus: RAPAEL Smart Board & Games

Out of the three rehabilitation game platforms that were routinely used at HRH (i.e., Rapael Smart Board, Rapael Smart Glove, and Smart Pegboard), this study focused on the Rapael Smart Board system [129]. The system is specifically designed to rehabilitate gross-arm movements in stroke survivors, which made it easier to visually analyze the interactions when compared to the other two platforms that focus on fine-hand movements. Furthermore, Rapael Smart Board has previously shown to be effective in improving the functional level and range of motion in stroke survivors [100].

System Configuration. Smart Board is composed of (1) an 18-inch touchscreen tablet computer and (2) a tabletop board with two degrees-of-freedom cylindrical handle (i.e., a controller for patients), as shown in Figure 1(a). The handle is the only point-of-contact between the patients’ upper-limb and the game system, which measures the patients’ hand positions in the two-dimensional horizontal plane. In terms of mechanics, the Smart Board controller is similar to the controller of end-effector style upper-limb rehabilitation technology solutions that are widely used in the hospital setting, such as InMotion Arm (Bionik Laboratories Corp., Canada) [71] and Armeo (Hocomo AG, Switzerland) robots [31]. The size of the board is $16.1 \times 11.2 \times 4.8 \, \text{cm}^3$. The system is
provided with a forearm support and a Velcro strap that can be used to assist stroke survivors with severe motor impairments (see Figure 3(a)). The forearm support helps patients to move their arm more easily against gravity. For patients with severe impairment in fine-hand movements, their hand and fingers could be strapped to the handle using the Velcro strap.

**Calibration of Game Play for Patients with Different Motor Impairment Levels.** Game-assisted therapy sessions begin with assessing patients’ upper-limb range of motion in a two-dimensional horizontal space (i.e., the Smart Board). During the assessment, patients need to voluntarily reach their hand (i.e., the handle) as far as possible to identify the boundary of their range of motion, based on which the positions of reaching targets in the actual game play are determined.

**Supported Games and Movement Monitoring.** The game play of Smart Board is controlled by patients’ hand position (i.e., the Cartesian coordinates of the handle). At the time of the study, Rapael Smart Board supported 17 different games. Five of these 17 games were designed to exercise the upper-limb range of motion. 9 were focusing on the shoulder-elbow joint coordination, and the remaining 3 were focusing on both the range of motion and joint coordination. All the games for Smart Board implement the traits of arcade video games, as shown in Figure 1, which are similarly used in other game-assisted rehabilitation tools, such as the games for the Armeo upper-limb rehabilitation robot [31]. Notable games that were frequently used in the observed therapy sessions include (1) the pet-feeding game (Figure 1(b)), in which patients need to make point-to-point two-dimensional reaching movements to move food to feed dogs and cats, (2) the dough-mixing game (Figure 1(c)), in which patients need to repeat circular hand movements following a visual trajectory (i.e., to remain inside the rim of a bowl) to make bread dough, and (3) the grocery-shopping game (Figure 1(d)), in which patients need to move around a grocery store by reaching to arrow keys that are displayed on the bottom of the screen and collect the asked grocery items again using point-to-point reaching movements. For all games, point-to-point reaching movements are considered successful if the distance between the patients’ hand position and target position becomes smaller than a system-defined threshold. Trajectory-following movements are considered successful if patients’ hand follow the suggested guideline while staying within the set boundary.

**Difficulty Adjustment.** Most games available on Rapael Smart Board support three different difficulty levels (i.e., difficult, normal, and easy) to personalize the therapy. For most games, the system modifies the difficulty level by adjusting (1) the number of targets presented on the touchscreen monitor and/or (2) the time limit for patients to complete the required exercise movements. Shoot ‘em up style games, on the other hand, had a larger number of difficulty levels (e.g., by adjusting the number and movement patterns of approaching missiles to avoid), which were automatically adjusted on-the-fly based on the patient’s game performance using a proprietary algorithm.

**Performance Reports.** Smart Board employs two different approaches to assess and report patients’ performance of game play (or equivalently, rehabilitation motor tasks). Whenever patients successfully reach a target for reaching motor tasks or stay within the provided visual guidelines for trajectory-following motor tasks, the game system adds points and displays the accumulated score on the touchscreen monitor. When a patient completes a game, the total score is again displayed on the monitor. Furthermore, therapists have access to patients’ performance of previously completed game plays via three different visualizations: (1) the regions that patients reached during the game play (i.e., two-dimensional range of motion), (2) the trace of two-dimensional hand trajectories during point-to-point reaching movements, and (3) the trace of hand trajectories during trajectory-following tasks. All the aforementioned measures and visualizations were computed...
Table 1. Summary of the Identified Themes, Subthemes, and Their Description

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme</th>
<th>Description</th>
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<tbody>
<tr>
<td>Engagement Patterns of Patients in Game-Assisted Therapy (Section 4.1)</td>
<td>• Misdirected Gamers</td>
<td>Patients show four different engagement patterns while participating in game-assisted rehabilitation therapy.</td>
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<tr>
<td></td>
<td>• Attentive Cooperators</td>
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<td>• Inattentive Bystanders</td>
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<td>• Old-Fashioned Enthusiasts</td>
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<tr>
<td>Critical Roles of Therapists as the Orchestrator (Section 4.2)</td>
<td>• Designing the Therapy</td>
<td>Therapists show four different roles to maintain patients’ engagement level and ensure therapeutic gain during game-assisted therapy.</td>
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<td>• Instructing the Game Play</td>
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<td>• Correcting Inappropriate Movements</td>
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<td>• Cheering the Therapy</td>
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<tr>
<td>Therapists’ Challenges and Needs (Section 4.3)</td>
<td>• Challenges to Prepare the Game Systems</td>
<td>Therapists experience three types of practical challenges while administrating game-assisted rehabilitation therapy.</td>
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<td>• Challenges in Run-Time</td>
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<td>• Challenges from Lack of Understanding of Therapists’ New Roles in Game-Assisted Therapy</td>
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under the assumption that the affected shoulder of patients is properly aligned to the origin of the games’ coordinate system.

3.5 Data Collection and Analysis

In total, we gathered 11 video-recordings of therapy sessions that amount to 5.5 hours and 15 audio-recordings of interviews with therapists that amounts to 7.5 hours. The entire video- and audio-recordings were transcribed and translated from Korean to English by the first author. The resulting transcripts, especially those that were used in the manuscript, were reviewed by the coauthors. If coauthors found that the translation did not appropriately deliver the intended nuance, the translation was revised and re-shared. The transcripts of the video-recordings included the contextual information (e.g., the room layout, the positions of therapists and patients, and whether patients used wheelchair or arm supports), non-verbal (pauses, sighs, laughter, gestures, physical interactions among therapists and patients) and verbal information (e.g., a monologue by therapists and dialogue between therapists and patients). Four authors (HJ, TP, NM, and SL) participated in an iterative process of data analysis using Thematic Analysis [18]. The first author (HJ) coded the data. Then, the four authors together reviewed the codes and discussed the potential themes that could best explain the observed phenomena in a series of meetings until the four authors came to an agreement on the themes.

4 FINDINGS

As a result of the analysis, we extracted a total of 481 codes from both the video and interview data and identified three themes, which are summarized in Table 1: Theme 1, four different engagement patterns of patients in game-assisted therapy; Theme 2, the leading roles of therapists throughout game-assisted therapy; and Theme 3, challenges faced by therapists while facilitating patient-centered game-assisted therapy. Both the video-recorded and interview data were equally used to derive the themes, especially Themes 2 and 3. For Theme 1, the video data were primarily used to support our analytic findings that were drawn from the interview data, because the interview data provided a more comprehensive understanding of various patient engagement patterns from therapists’ lived experience compared to only a limited number of engagement patterns observed in the video data. We discuss each theme in detail in the following subsections.
4.1 Engagement Patterns of Patients in Game-Assisted Therapy

We observed stroke patients' attitudes and engagement patterns in game-assisted rehabilitation therapy. Based on our results, we classified stroke patients into four different groups, which include (1) misdirected gamers, (2) attentive cooperators, (3) inattentive bystanders, and (4) old-fashioned enthusiasts (Figure 2). We further discuss the engagement patterns and characteristics of each group, as well as how those patterns affect the therapist-patient interactions and the potential benefits of game-assisted therapy.

**Misdirected Gamers.** From the interviews with therapists, we could identify a group of patients who were engaged with games mainly for entertainment rather than therapy. The interviewed therapists believed that, in general, patients' engagement level could be enhanced during game-assisted therapy when patients have a sense of ownership in selecting games. However, according to therapists, more ownership does not always lead to therapeutically meaningful exercises.
Some patients have strong opinions on the time duration and the set of games they want to do. When they don’t find the game interesting, they just don’t do [the movements] any more after trying a couple of times. [...] They have their own way of playing games. [...] They also have a sequence of games they have to play. [...] It’s really difficult [to moderate game-assisted therapy sessions] with strong-willed patients. – T3

The games that these patients prefer often involve exercise movements that are physically easy for them to perform and have minimal therapeutic impacts on the stroke-affected motor function. Therapists would first try to persuade these patients to play (or equivalently exercise) therapeutically more appropriate games (movements).

I try to reduce the time duration of playing those games [that are not beneficial to patients] and convince patients to play therapeutically more beneficial games for them. I say “What about another one? Would it be okay to play this one?” – T3

In response, such strongly opinionated patients would even let go of the game handle and refuse to engage, explicitly expressing annoyance and saying, “I’m not going to do it,” as one therapist mentioned (T14). According to therapists, such conflicts on selecting appropriate games lead to emotionally charged interactions between therapists and patients. This becomes especially amplified when patients keep insisting on playing games they like and pursuing entertainment.

I end up raising my voice and go like “You should do this game! Why won’t you try this? Other games are no good for you! You have to practice this movement [supported by the game]! If you are not going to do this, there is no reason to use this Smart Board at all!” Then patients go mad like ‘Boom!’ – T7

When these patients play the games they want, they would simply play and enjoy rather than exercise arm movements induced by the game. According to therapists, patients would recruit extremely abnormal compensatory behavior when they lose attention to their movement quality. For instance, T4 stated, “They even use both [affected and unaffected] hands [to move the game controller].” Another therapist shared a similar experience:

When patients focus on playing games too much, they totally forget about their postures. – T7

The same therapist first demonstrated proper movements in an upright sitting posture, followed by exaggerated compensatory movements of swinging her trunk and said, “In this posture, you need to move your arm like this. However, they are like ‘bang bang bang,’ almost breaking the controller.” Other therapists further supported that patients who are overly engaged in games recruit significant compensatory behaviors. When therapists try to correct patients’ movements, some patients explicitly resist, as one therapist explained:

I wanted to correct his posture, but then he said, “I don’t want to pay attention to any of those. I just want to do it the way I want.” – T12

Since such a demeanor could result in physical struggle and resistance, therapists would wait until the patient finishes the game, as one therapist stated:

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Readers are referred to the definition of compensatory behaviors in Section 2.2.
When I lay my hand over his shoulder and try to suppress compensation, he shrugs off my hand and does not let me touch him. […] What do I do for that patient? I cannot really do anything until he finishes the game. – T7

Consequently, when patients have strong opinions on selecting games and overly engage in the entertaining aspect of the games, therapists could struggle to properly administer game-assisted therapy in a way that benefits the patients. In turn, patients may neither practice therapeutically appropriate exercise movements nor achieve functional gain. More importantly, serious game-assisted rehabilitation therapy in stroke survivors may induce the development of therapeutically undesirable compensatory behaviors for some overly engaged patients if they are not closely supervised by therapists, which could even be detrimental to their functional recovery.

During the interviews with the therapists, we also asked them to provide a rough estimate of the percentage of patients who would show a specific engagement pattern among the patients they had seen throughout their game-based therapy sessions. Therapists said approximately 1–2 out of 10 patients would show the engagement characteristics of misdirected gamers who express strong opinions about what and how they wanted to play games. We relied on therapists’ recollection to estimate the prevalence of the engagement patterns because (1) the number of patients involved in this study was relatively small to draw any significant statistics and (2) some engagement patterns—such as misdirected gamers and old-fashioned enthusiasts—were only evidenced in the interview data but not in the video data (e.g., misdirected gamers and old-fashioned enthusiasts were removed from game-assisted therapy soon after their engagement traits had been identified.)

**Attentive Cooperators.** Another patient group that we identified includes those who would cooperatively follow the lead of therapists and accept their suggestions during game-assisted therapy. Patients in this group are willing to try the games that therapists suggested, even though they may not like the recommended games.

> Patients would tolerate [the games] even if they don’t like [them]. […] They don’t say “no.” – T4

For these cooperative patients, therapists occasionally ask for patients’ preferences and opinions in choosing a game in an attempt to provide more ownership of the therapy to patients, hence enhancing their engagement level. However, according to therapists, only 2–4 out of 10 of these patients would actually express their preferences to therapists, and the remaining 6–8 patients would ask therapists to choose the most therapeutically appropriate games for them (T2), demonstrating a strong emotional bond and trust with their therapists (referred to as rapport). Therapists supported that they often establish a strong rapport with attentive cooperators and emphasized its importance in game-assisted therapy as much as in conventional therapy.

> They do what you ask to do when you establish a good rapport. However, if not, they are not going to do what you ask. […] There was a patient. When he practiced with me, he tried to reach 5 cm more [than he could comfortably do]. However, when he practiced with other therapists, whom he didn’t have a good rapport with, he would try just a little and give up. – T8

In one video-recorded therapy session (V3), cooperative interactions based on good rapport were witnessed throughout the game-assisted therapy session. Both the patient and the therapist enjoyed game play with cheerful laughter and friendly conversations, while the patient listened and tried to reflect the therapists’ verbal and physical feedback during game play.

We asked therapists for potential factors that could have contributed to these patients’ high engagement level and cooperative attitude. Therapists stated that attentive cooperators usually
include those patients who are in their early stages of recovery and thus are particularly motivated to improve and return to their normal life.

_When patients just had a stroke, they are like “I have to get better quickly and go back home.”_ – T10

From our interviews, therapists also stated that cognitive and motor impairment levels are other important characteristics of patients in this group. Therapists said that _attentive cooperators_ often have moderate cognitive impairments. For instance, as will be discussed later, patients with severely impaired cognitive function will not be able to engage (see _inattentive bystanders, sub-type B_), whereas some patients with good cognition perceive rehabilitation games as childish (see _old-fashioned enthusiasts, sub-type D_). Therapists also stated that _attentive cooperators_ often have moderate motor impairment levels. Patients with severe motor impairment often feel that the performance of active exercise movements (i.e., voluntary arm movements without physical assistance from therapists) is especially difficult and, consequently, lose interest in game-assisted therapy quickly (T4). On the other hand, patients with specifically good motor function could easily complete the games and become bored of game-assisted therapy (T4). Therapists also explained that _attentive cooperators_ often have prior experience with computers and games (T11).

We asked therapists if rehabilitation games would provide added values if patients were already motivated and cooperative. T9 responded, “Yeah, they have greater motivation in game-assisted therapy than in conventional therapy.” Overall, therapists believed that games would further improve these patients’ adherence to the rehabilitation program as a whole.

**Inattentive Bystanders.** The next patient group we identified include those who do not engage in conventional nor game-assisted rehabilitation therapy. For these patients, games do not provide any added merits or motivation for them to actively participate in the rehabilitation process. Based on the interviews with therapists, we further identified two sub-types of patients within this group. The first sub-type includes patients who have poor motivation for rehabilitation in general (i.e., patient sub-type A in Figure 2), and the second sub-type includes those who have severely affected cognitive function (i.e., patient sub-type B in Figure 2).

Therapists explained that the first sub-type of patients often had prolonged motor deficits since their stroke (e.g., more than several years). As a result, these patients have low expectations for potential recovery and show a poor motivation to engage in therapy. T11 stated, “If it has been a while since their stroke and if they are in their chronic stage, […] they are like ‘What can be improved?’.” Therapists believe that the use of rehabilitation games do not provide any notable improvement in the motivation level or adherence to the therapeutic regimen for patients who initially have poor motivation in conventional therapy. T14 stated the following while demonstrating a leaning posture:

_I initially thought that games would motivate those who were not motivated. However, when patients didn’t really have any motivation, they would just lean back and stay like this [during game-assisted therapy]._ – T14

Indeed, in one video-recorded therapy session, the patient was minimally engaged throughout the game-assisted therapy session even when the therapist verbally encouraged the patient and directed her attention to rehabilitation games and game-induced movements (V10). The therapist expressed her frustration and sighed multiple times as her patient stayed disengaged despite her continuous efforts:

_What can I do for you? […] Please, please. […] You are not really focusing at all._ – V10
Another therapist shared similar experiences during the one-on-one interview:

Some patients simply want to receive a therapeutic massage. They just say “Give me a massage. I don’t want anything other than a massage.” […] Even though we take them to game-assisted therapy sessions, they won’t make any voluntary movements. We end up giving them massages in front of Smart Board. – T15

Indeed, in one video-recorded therapy session, the patient received a therapeutic massage throughout most of the game-assisted therapy sessions and was involved only in passive reaching movements where the therapist physically assisted the patient’s upper-limb movements (V4). Rehabilitation games were not used at all in the session.

According to therapists, patients with severely affected cognitive function (i.e., patient sub-type B) would have a hard time understanding how to play games and perform the instructed movements:

To be honest, only a small group of patients are eligible for such game-based therapies. You need to have at least some cognitive function to understand how to do those games. […] Because of poor cognition, there are many games that patients cannot really do at all. – T1

Patients would refuse to participate in game-assisted therapy when they cannot comprehend the game play instructions. T3 said, “Patients with poor cognition don’t seem to have an interest in games. When they have a hard time [understanding], they look irritated and say, ‘Let’s just go back to my room.’” Even when some patients participate in game-assisted therapy sessions, the games would not provide any added values or merits to the therapeutic activities, according to T13’s comment: “They just keep looking at my [demonstrating] hands and not the screen. […] They try to imitate my hand [movement] because they don’t know how to do [the expected exercise movements]. She only does what I tell her to do.”

In sum, for inattentive bystanders, games do not effectively improve motivation or engagement to rehabilitation. Therapists explained that they usually discontinue game-assisted therapy for these patients and instead provide them with passive therapy, such as therapeutic massages or physically-assisted exercises.

Old-Fashioned Enthusiasts. The last group of patients includes those who prefer conventional, non-game-assisted therapy over game-assisted therapy. According to therapists, 1–2 out of 10 patients fall into this group. Therapists suggest that these patients are aware of the importance of active engagement in the therapeutic regimen and already passionately participating in conventional rehabilitation therapies. From the interviews with therapists, we were able to further identify two different sub-types of patients in this group (i.e., patient sub-types C and D in Figure 2). The first sub-type of patients (i.e., patient sub-type C) believes that they could work hard and make motor improvement without the assistance of games since the practiced exercise movements are essentially the same. In addition, according to therapists, these patients are attentive to maximally utilizing the limited therapy time with therapists and do not want to reduce the net practice time by adopting games.

Some patients say that games are not really necessary because they can do [the same exercise movements in conventional therapy sessions] just with therapists. They say they can practice those movements and believe, “It’s just a matter of using games or not.” […] They do not want to waste even a single minute of their [30-minute] therapy session. – T10
In our study site, the rehabilitation game-equipped room was located on the sixth floor. If patients were on different floors, therapists had to bring them to the sixth floor, and the travel time was counted as part of the 30-minute therapy time. Many patients also had impairment in their gait and had to use an elevator, which could take up to several minutes. This resulted in reducing the net exercise time and influenced patients in this group to prefer conventional therapy over game-assisted therapy. T10 stated, “It’s not like they are negative to rehabilitation games. They like games, but it’s quite inconvenient for them to come all the way up [to the sixth floor].”

Therapists describe the second sub-type of old-fashioned enthusiasts (i.e., patient sub-type D in Figure 2) as those perceiving rehabilitation games as inappropriate for their dignity (e.g., considering games as more appropriate for youngsters).

Some patients with good cognition say, “This is a toy for kids. What are you going to do with this to me?” […] They mention “I want therapy. Not this [game]. I want to receive real therapy.” – T7

Another therapist shared a similar experience.

I wanted him to practice the movements [that are supported by some games], but he didn’t like them because games looked childish to him. He said, “Do I really have to do this?” – T8

When therapists were asked for the potential reasons that may have caused such negative perceptions and attitudes of patients towards game-assisted therapy, therapists thought that the lack of patients’ prior experience with computer and video games could be one of the factors. T4 stated, “You know, these patients have never played video games before.” We asked therapists if previous exposure of patients to traditional, non-computerized games, such as card or board games, would lead to a positive attitude towards rehabilitation games. Therapists explained that patients might not want to engage in rehabilitation games even if they enjoy conventional games.

Those who play real card games, like pokers, think rehabilitation games are childish. Because of fine motor impairment, they really have a hard time holding cards. Nevertheless, they still try hard to play those card games but not rehabilitation games. – T9

Another major factor that influences these patients’ negative perceptions towards serious games could be the style (cartoon-like) of graphics used in the games. T8 said, “We think these patients could benefit from practicing with Smart Board, but they think gaming graphics are too childish.” Indeed, most of the Smart Board games incorporate cartoon-like graphics. For instance, the pet-feeding game employs cartoonized dogs rather than the photos of real dogs. One notable exception is the tessellation jigsaw puzzle game, where the pictures that patients are asked to complete are the photos of real objects, such as flowers or mugs.

4.2 Critical Roles of Therapists as the Orchestrator

Our analysis revealed that therapists play comprehensive and orchestrating roles during therapy sessions to maximize clinical outcomes for their patients. We identified four major roles of therapists in game-assisted clinical rehabilitation, which include (1) designing the therapy, (2) instructing the game play, (3) correcting inappropriate movements, and (4) cheerleading the therapy.

Designing the Therapy. We found that therapists strategically prepare game-assisted rehabilitation sessions to provide personalized, patient-centered therapy by selecting which games to play (or equivalently, which exercises to perform), the difficulty levels, and arranging assistive tools (i.e.,
a forearm support and Velcro strap) to support patients’ different impairment level. Furthermore, therapists actively adjust their designs during the therapy sessions based on patients’ responses to the regimens. The interviews with therapists revealed that they try to balance patients’ engagement levels and therapeutic benefits by selecting a combination of entertaining games that patients prefer and games that therapists deem therapeutically meaningful (i.e., negotiating with patients).

*I let them play what they want for three minutes and ask them to play what they need to play for six minutes in return. I repeat this within the therapy session to keep their engagement and yet make the overall session more therapeutically meaningful.*
– T9

Furthermore, while therapists try to actively incorporate patients’ preference in selecting games, therapists mostly control the difficulty level to maximize the therapeutic outcomes.

*I control the difficulty level most of the time. [...] When patients seem to do well, I would stop the game and restart at a higher difficulty level.*
– T3

Indeed, in all the video-recorded therapy sessions, the therapists controlled the difficulty level without asking their patients. Therapists were asked for the reasons that they would not offer patients complete freedom to choose games. Therapists answered that their selection of games would be essential to ensure clinical relevance and benefits of game-assisted therapy.

*If I completely leave [selecting games] to patients, wouldn’t it lead to poor recovery? If patients practice games that challenge the cognitive aspects more while they need to improve their range of motion, it wouldn’t be much helpful. Most patients cannot make such decisions on their own.*
– T1

Therapists further explained that patients, including the attentive cooperators, show a preference for the games that they have played before, or the associated exercise movements are easy to perform rather than exploring for therapeutically challenging games.

*Patients rarely choose difficult games. They usually choose the games that induce the movements they can do easily.*
– T11

Therapists selectively choose to use assistive tools (i.e., a Velcro strap and a forearm support) to accommodate patients’ motor impairment levels, so that patients can better focus on the specific motor function that therapists aim to practice. When patients have difficulty grasping and holding on to the controller (i.e., poor fine-hand function), therapists use a Velcro strap to affix the patients’ hand to the controller, so that patients can focus on regaining gross-arm function. T4 described, “When patients don’t have a strong grip, we wrap a Velcro strap around their hand and the controller. We selectively use the strap to adjust the level of support for patients.” When patients’ gross-arm motor functions are severely deteriorated, therapists use the forearm support attached to the handle in order to attenuate the amount of gravity so that patients can perform gross-arm movements more easily. In the video-recorded sessions, 3 out of 11 patients used a forearm support (V2, V4, and V8), and 9 out of 11 patients used a Velcro strap throughout the game-therapy sessions (all the videos except V3 and V5). Figure 3(a) shows a patient who used both the forearm support and the Velcro strap, and Figure 3(b) shows a patient who could voluntarily grasp and practice movements against gravity without the assistive tools. These findings collectively shed light on the importance of therapists’ strategic decisions in personalizing game-assisted therapy for individual patients. As patients’ motor functions improve over time, therapists would adjust
Instructing the Game Play. Our analysis revealed that therapists employ various approaches to provide additional instructions regarding game-related rules to their patients—especially for those with cognitive impairments—despite games providing visual instructions on the screen via text and animated images. Therapists communicated their instructions using the following three different methods: verbal, gestural, and hands-on physical assistance.

During the calibration procedure to measure the range of motion (see Section 3.4), therapists often verbally instructed patients to induce the maximum voluntary range of motion. For instance, in one video-recorded session (V2), the therapist made an analogy between the expected hand movement and painting: “Let’s paint the screen. Move [your hand] back and forth.” In combination with verbal explanations, therapists physically demonstrated the expected movements for the range of motion assessment. For instance, in V1, the therapist swung her arm from left to right in the air while saying, “Let’s make a big circle from your left to your right. […] Let’s try one more time. […] Yes, you’re making a beautiful circle.” When patients did not comprehend the instruction from the verbal or gestural explanations, therapists also provided physical assistance by placing their hand over the patient’s hand and moved together until the patient understood the instruction (V2).

A similar pattern of instructions was observed while patients were engaged in the actual game play. Especially when games simultaneously provided multiple visual stimuli on the screen, patients demonstrated difficulty directing and maintaining their focus on the appropriate visual stimuli (e.g., targets to reach). As a consequence, therapists had to repeatedly direct the patient’s attention to the appropriate visual stimuli or explain their meaning throughout the therapy sessions. For instance, in a shoot ‘em up style game, patients had to avoid missiles and stay alive to advance to higher stages and gain higher scores. In one video-recorded session (V3), the patient chased missiles rather than avoiding them. The therapist repeatedly explained the game rules and expected movements to the patient:

[Missiles are] Incoming. Incoming! No! Dodge! […] Get out [of those missiles]. Don’t dive into missiles. […] When you touch them, you will die. – V3
The therapist made pointing gestures to direct their patients’ attention to the correct targets on the screen (Figure 4(a)). In another video-recorded therapy session, the patient had difficulty locating the reaching targets on the screen, and the therapist had to continuously point at the targets throughout the session (V8). Sometimes, patients did not reach all the way to the targets and stopped their movements in the middle. In such cases, therapists physically assisted their patients to complete the movements. For instance, in V5, the therapist placed her hand over the patient’s hand and moved to the target together while verbally explaining, “Here. All the way here. Go and follow the arrow.” (see Figure 4(b)). As described herein, due to patients’ limited cognitive capacity, therapists’ additional instructions are necessary to help patients understand, follow, and play games.

Correcting Inappropriate Movements. Another important role of therapists during game-assisted therapy is to correct patients’ improper postures and suppress abnormal compensatory behaviors in order to induce therapeutically more meaningful exercise movements. T2 quoted,

> Honestly speaking, I believe posture is the most important thing that patients need to pay attention to. […] I always start correcting patients’ posture. […] That may negatively affect the engagement of patients [in playing games]. But, even if you execute a movement just once, I think it is important to do it in the right way. – T2

Indeed, in the video-recorded therapy sessions, it was frequently observed that therapists provided their patients with detailed verbal explanations to yield therapeutically desirable movements.

> Don’t lean back. Keep your trunk away from the chair-back. […] Reach [your hand forward]. […] Don’t do it with your trunk. […] Now, bring [your hand] back. Your trunk should stand still. […] You need to move your hand back. – V6

In addition to verbal explanations, therapists may provide physical feedback to patients as needed. For instance, in one video-recorded therapy session (V11), the therapist gently tapped on the patient’s back and said, “sit up and open up your shoulders” to induce an upright sitting posture when the patient started to slouch (Figure 5(a)). For patients who employed significant compensatory behaviors, therapists went beyond the gentle tapping and physically suppressed patients’
compensations. In another video-recorded session (V8), the therapist pushed against the abnormally lifted shoulder with the left hand, and grasped and pulled the patient’s hand to the reaching target with the right hand in order to enforce a therapeutically desirable reaching movement (Figure 5(b)).

When we asked therapists for the reasons that they emphasize therapeutically appropriate postures and movements, therapists answered that such movements are essential in yielding the true motor recovery and minimizing undesired pain or injury, especially when the engagement factors of the games stimulate and influence patients to maintain their entertainment values (e.g., to be able to continue their game play or obtain higher game points) with clinically undesirable movements (e.g., compensatory behaviors).

Patients feel forced to make movements quickly in game-assisted therapy and tend to recruit muscle groups in atypical manners. It can cause additional pain. – T13

The same therapist further explained that such pain may serve as a major factor to disengage patients from game-assisted therapy sessions.

They say, “It hurts again. I don’t want to do it.” […] Patients wouldn’t know what they are doing wrong unless we tell them. – T13

These findings support the imperative role of therapists in supervising and intervening to promote patients’ appropriate postures and movements, thereby maximizing the therapeutic outcomes.

Cheerleading the Therapy. Another important role of therapists in game-assisted therapy includes their efforts to applaud patients when they perform therapeutically-appropriate movements, comply with therapists’ feedback, and/or successfully complete a game with good performance. In one of the video-recorded therapy sessions (V1), when the patient demonstrated smooth joint elbow-shoulder coordination during a reaching movement, the therapist complimented by saying, “That was a nice stretch of your elbow. Wow, you didn’t hit anything. Nice!” In another video-recorded therapy session (V6), the therapist complimented the patient when he successfully complied with the feedback: “Try to move your hand forward and backward. Come all the way back. […]”
When the patient successfully cleared a game stage, the therapist cheered and clapped (Figure 6(a)) in addition to the game-provided audio-recorded fanfare and animated graphics (V2). In one video-recorded session (V6), the therapist suggested a high five after the patient successfully completed a game (Figure 6(b)).

When we followed up with therapists for the reasons that they provide additional encouragement, therapists first explained that, given a pool of games, patients end up repeatedly playing only a small subset of games that are relevant to their specific impairment condition. T13 said, “There is no patient who plays all 17 games. There’s only a limited number of games that each patient needs to practice. […] Patients are often left with only three-to-four games to play.” Therapists argued that patients often lose interest in game-assisted therapy after some time, and therapists have to provide extra cheerleading to motivate patients and improve their adherence to the therapeutic regimen.

*When you play games every day, you get so used to them. It’s not just patients. I think anyone would be bored. […] When I compliment and cheer for patients, they seem less bored and doze off less during the therapy.* – T8

### 4.3 Therapists’ Challenges and Needs

As we discussed in the previous subsection, therapists play key roles in enabling effective game-assisted therapy. In this section, we identify three major challenges that therapists experience as a leading user of the rehabilitation game system while administering patient-centered therapy. The challenges revolved around (1) challenges to prepare the game system, (2) challenges during run-time, and (3) challenges from lack of understanding of therapists’ new roles in game-assisted therapy.

**Challenges to Prepare the Game System.** Our video-recorded data showed that therapists had to align patients to the coordinate origin (i.e., the centerline) of the Smart Board prior to every game-assisted therapy session to personalize the system based on the patients’ anthropometric characteristics (e.g., sitting-height). The alignment is particularly important because the Smart Board games provide graphical feedback of patients’ hand positions (e.g., the location of the jet fighter in a shoot ‘em up style game) based on the assumption that patients are properly aligned to the Smart Board. First, therapists positioned patients to the centerline of the system to face
the monitor. In the observed video-recorded sessions, most patients used wheelchairs and were not physically able to self-align to the system, so therapists operated the wheelchairs to perform the alignment. Then, therapists adjusted the height of the table, on which the Smart Board was placed, to patients’ sitting-heights. Since there were no visual references that therapists could use to find the correct alignment, it was possible that patients were imperfectly aligned to the game system. Furthermore, most of the wheelchairs that patients used in the video data did not support the position adjustment of the arm supports (all except V1, V3, and V12), which obstructed the wheelchairs to be placed closer to the Smart Board. As a consequence, the distance between the Smart Board and the patient was significantly greater when compared to those who used wheelchairs or regular chairs with adjustable or unobtrusive arm supports. Potential misalignment could introduce (1) a discrepancy between patients’ actual movements and the game system’s measured movements within each therapy session and (2) inconsistency in the measure of patient performance across multiple therapy sessions. T13 stated,

_The sensor measurement is significantly affected by where patients sit and face. [...] When the position of the chair [that patients sit] moves, patients’ same movements are measured differently._ – T13

Subsequently, incorrectly measured hand movements can cause significant difficulties for therapists to moderate therapeutically important exercise movements. T15 commented,

_When patients are not facing the front direction correctly, their movements and the game cursors do not match. [...] Stroke patients often don’t have a normal cognitive function and don’t comprehend their movements well. [...] They simply believe that the perceived cursor movements and their own hand movements match._ – T15

Furthermore, therapists emphasized the importance of consistent alignment across multiple therapy sessions, particularly when different therapists had to see the same patient (T12). For instance, when the designated therapist for a patient has a day off, a peer therapist has to substitute the game-assisted therapy session (T12). The inter-therapist variability in the alignment could lead to different measurements of motor performance. Consequently, the summary (and trajectory) of a patient’s motor performance generated by the Smart Board system may not reflect the patient’s actual motor ability. T14 commented that “Movement measurement depends on how patients sit. [...] Although patients’ performance is consistently getting better, the performance shown in the game-generated reports may fluctuate over time.” Such inconsistency may lead to therapists’ and patients’ distrust of game-generated reports on patients’ performance, as T13 stated:

_To be honest, I end up not checking the [game-generated] reports. [...] I don’t really trust [the reports]._ – T13

Indeed, most therapists did not review the game-generated performance assessment report throughout the game-assisted therapy session. Those who reviewed the reports only briefly mentioned the total score that the patients achieved from each game (V2 and V12). In our interviews, therapists argued that observable and tangible references need to be provided by the game system to properly align patients. One therapist proposed an idea of integrating the Smart Board with a table and a chair, positions of which could be explicitly controlled by therapists.

_A table and a chair could have been integrated with Smart Board, and their positions could be controlled like up, down, forward, and backward. [...] They could be integrated as a complete package._ – T13
The findings reported in this section demonstrate that even a simple rehabilitation game system with only two degrees of freedom (i.e., a handle moving in a two-dimensional space) needs careful preparation and arrangement in order to yield appropriate therapeutic outcomes and accurate measurements of motor performance. It is particularly important that the game system provides a convenient way for therapists to adjust the system to the patient’s physical and anthropometric conditions, or otherwise becomes a great burden for therapists to enable personalized, game-assisted therapy.

**Challenges in Run-Time.** Therapists often face difficulty while delivering personalized game-assisted therapies for individual patients when therapeutic goals set by the therapists are not well supported by (1) the system-provided variables determining the difficulty level of game-induced movements and (2) the criteria evaluating patients’ performance of exercise movements. Furthermore, game system’s limited user interface for therapists—the leading user of the rehabilitation game system—to interact with and control the game system during run-time could hamper the effective moderation of therapy sessions.

In order to adjust the difficulty level of game-induced exercise movements in Rapael Smart Board, therapists were given a single variable: selecting one of the three stages of increasing difficulty levels that was preprogrammed into the games. When this variable did not adequately support the therapeutic goals set by therapists, therapists were not able to deliver the therapy that they deemed appropriate for individual patients. Patients often need to practice different aspects of movements, such as the ability to precisely control hand movements, a greater range of motion, or faster and smoother movements (T2, T6, T7, and T12). However, the preprogrammed difficulty level of the Smart Board games was designed to mainly challenge patients’ movement speeds by either adding more targets to reach within a given time or decreasing the time duration within which patients need to complete the motor task. T2 provided an example with the jigsaw puzzle game, in which patients assembled tessellating pieces to produce a complete picture. “When you select a more difficult stage in the jigsaw puzzle game, less amount of time duration is given to patients until they could completely assemble the puzzle.” In the current jigsaw puzzle game, patients were given 15, 10, and 5 seconds in the easy, normal, and difficult stages respectively, until they could complete the puzzles. T2 said she would reduce the size of each tessellating piece instead of providing a shorter time to complete the tasks so that patients could practice finer control of their upper-limb movements rather than simply practicing faster movements. She further stated that such a discrepancy between personalized therapeutic goals and the preprogrammed goals in games could lead to therapeutically undesirable consequences.

*If [the game] focuses too much on patients’ movement speeds, then [patients] end up employing significant compensatory movements and making less precise movements.*
– T2

T6 shared a similar experience. The therapist wanted a patient to practice a larger range of motion, but the preprogrammed game configurations could not support the exercise. The therapist gave an example with the constellation-drawing game in which a set of stars (i.e., reaching targets) are displayed, and patients have to sequentially connect the stars to complete a drawing of a constellation. This game changed the number of stars to adjust the difficulty level rather than placing them further away to practice a greater range of motion, which may be more relevant to some patients depending on their motor condition. The therapist explained that he ended up re-calibrating the system to increase the measured range of motion beyond that of the patient’s active range of motion (see Section 3.4 for details regarding the calibration process). Such a “hack” enabled the games to place the reaching targets further away from the patient and induced a greater range of motion.
The interviews with therapists also revealed that the Smart Board’s criteria to determine patients’ successful movements did not always conform to the criteria of therapists. For example, in point-to-point reaching exercise movements, games considered a reaching movement successful as long as a patient’s hand (i.e., the handle) reached the target. In contrast, therapists considered a reaching movement successful only when its quality (e.g., smoothness, speed, or presence of compensatory behaviors) was satisfactory. For instance, one therapist described,

*When I saw [a patient’s movements], the patient didn’t really do movements correctly. […] Even when the patient used compensatory movements, games said the movements were successful, and I talked to myself like “Ah, that’s not it.”* – T12

Consequently, therapists ended up correcting patients’ exercise movements based on their own evaluation of motor performance (see Correcting Inappropriate Movements in Section 4.2 for details), rather than simply relying on what was provided by the games. Indeed, in all the video-recorded therapy sessions, the therapists provided a mixture of verbal and physical assistance to induce therapeutically desirable movements as needed, even if the movements were determined successful by the games.

In our observation, therapists demonstrated difficulty interacting with the game system to control variables to enable personalized therapy, mainly due to the system’s limited interaction interface. As we previously discussed, therapists often sit next to or behind the patient (e.g., Figure 5) to orchestrate the therapy session. However, the touchscreen of the game system was located across the Smart Board controller, which was out of the therapists’ reach. Therapists ended up utilizing a third-party wireless mouse to interact with the game system in an uncomfortable manner (see Figure 7). Therapists often placed the mouse on the edge of the table, on which the Smart Board was placed, the Smart Board itself, or on their lap so as not to interrupt patients’ exercise. During the interview, they expressed their frustration about the limited interfaces of the rehabilitation game, which did not consider therapists as a leading user (T2, T3).

The findings reported herein suggest that therapists may be able to moderate therapy sessions more effectively if the game system provides (1) flexibility in adjusting and customizing game-induced exercise movements to individual patients’ motor deficits, (2) more accurate and clinically
relevant evaluation of patient’s motor performance, and (3) a comfortable means to interact with the game system.

**Challenges from Lack of Understanding of Therapists’ New Roles in Game-Assisted Therapy.** Our findings in the previous sections showed that therapists go beyond merely helping patients to play rehabilitation games but to administer the entire game-assisted therapy sessions. In our interviews, therapists strongly expressed the need for proper education or training to learn how to effectively utilize rehabilitation games as a therapeutic tool. For instance, a first-year therapist, T14, stated:

*My first exposure to rehabilitation games was during my internship. When I joined [Heeyeon Rehabilitation Hospital], I did not know what to do [in game-assisted therapy]. […] There were no textbooks. No professors taught me how to do therapy using rehabilitation games when I was in college.* – T14

The same therapist said that they identified their roles in game-assisted therapy based on the lived experience of senior therapists or their own trial-and-errors.

*I had to ask other senior therapists. […] I struggled a lot. […] I think I should just try more.* – T14

Another therapist also concurred and explicitly emphasized the necessity of formal training on game-assisted therapy.

*When you get to use [the rehabilitation games] right away [without any training], you won’t know if you have to actively provide physical assistance to address patients’ compensation. […] If there is some training on game-assisted therapy, then therapists can be aware of their roles more clearly. Such training will lead to more efficient use [of the rehabilitation games].* – T8

We asked therapists for any undesirable consequences that could occur due to the lack of understanding or proper training. Therapists explained that the inappropriate use of rehabilitation games could cause negative side effects, such as pain or injury.

*The use of games can cause pain or injury when rehabilitation games are inappropriately used. So, it’s important for therapists to understand the specifics of game products and appropriate ways to apply them. […] This makes it difficult, especially for those who are new to game-assisted therapy.* – T13

Another therapist shared her own experience such that inappropriate use of assistive tools (e.g., wrapping a Velcro strap) by incompetent therapists could lead to reduced net therapy time and patients’ distrust in therapists, both of which could significantly affect the outcomes of game-assisted therapy.

*A patient talked to me the other day. She said that she felt quite bad when incompetent therapists administered her game-assisted therapy. […] She asked me if I could take over or teach her therapist [how to deliver therapy in game-assisted therapy]. […] When her hand gets out of the strap, then she’s losing [the net therapy] time again.* – T7

These findings collectively suggest that clear identification of therapists’ roles and appropriate, comprehensive training on the game platform is necessary to accelerate therapists’ learning curve and enhance the quality of game-assisted therapy sessions.
5 DISCUSSION

Our study reveals that patients exhibit different engagement patterns depending on the level of motor and cognitive impairments, as well as their interests in games and commitment to rehabilitation therapy. Each patient has unique motivating and demotivating factors, such as a propensity for entertainment values and preconceptions towards video games. Therapists strive to accommodate these patients at the forefront by playing multiple roles and, at the same time, experience a number of practical challenges. In this section, we situate our findings in relation to prior research findings and theoretical frameworks, mostly around the understanding of therapists’ encompassing roles and the challenges they experience, accommodating the different engagement patterns of stroke patients, and optimizing their therapeutic gains in game-assisted therapy. Then, we offer some design implications based on the reported findings and discussions.

5.1 Therapists’ Roles, Practical Challenges, and Needs for Training

Therapists’ Roles in Game-Assisted and Conventional Therapies. Although our study is the first to systematically analyze the lived experiences of therapists to understand their roles and practical challenges they face during routine game-assisted therapy in actual clinical settings, there have been a number of previous studies that suggested the necessity of therapists’ supervision during game-assisted therapy. Prior studies briefly mentioned therapists’ roles to prevent any potential exacerbation of pain or injury and to ensure the exercise quality in children with cerebral palsy and patients with multiple sclerosis [5], brain injury survivors (e.g., traumatic injuries) [22], and stroke survivors [106]. Deutsch et al. reported that the evaluation of patients’ exercise movement quality provided by COTS games (i.e., Nintendo Wii) was not adequate and recommended therapists to provide feedback [28]. Furthermore, Brütsch et al. showed that therapeutic outcomes were significantly better when therapists closely supervised robot- and game-assisted gait therapy sessions [20]. Our findings corroborate these acknowledged needs of therapists. In our study, we took a step forward to analyze therapists’ comprehensive, orchestrating roles as well as their strategies to moderate game-assisted therapy sessions. We found that therapists’ roles in game-assisted therapy do not appear to be much different from their roles in conventional therapy. In conventional rehabilitation settings, therapists need to identify attainable goals of improvement for patients, administer therapies to help patients achieve the goals, assess patients’ progress, and iterate the aforementioned processes until discharge [76]. In this process, therapists’ are responsible for designing therapeutic activities and adjusting their difficulty levels that best accommodate individual patients’ impairment characteristics [44, 94, 116], and for maintaining patients’ engagement and ensuring the quality of patients’ exercise movements [140, 144]. It is noteworthy that therapists believed that the use of rehabilitation games contributed to reducing the workload of therapists by automating the process of presenting exercise movements and observing and evaluating movements’ performance to some extent (T5). Also, therapists stated that, by employing rehabilitation games, it was easier to induce voluntary movements from patients (T8), build rapport by talking about game play (T9), and physically less-burdensome because they could use assistive tools to help patients exercise against gravity (T4, T11). However, an in-depth comparative analysis of therapists’ roles when games are used vs. not used in therapy, and the understanding of how games assist different roles of therapists remain as future work.

Practical Challenges that Therapists Face. Despite the acknowledged needs of therapists in game-assisted therapy for stroke survivors, there is only a limited understanding of practical challenges that therapists experience. Our findings demonstrate the importance of and therapists’ challenges to properly aligning patients to the game system for accurate monitoring of movements. The importance of patient-to-game alignment has been similarly acknowledged in a study by Geurts
et al. [40], which studied the application of camera-based or wearable sensor-based COTS games in patients with spasticity. Our study also reported therapists’ challenges in adjusting the difficulty level of games to design personalized rehabilitation programs that can specifically focus on different impairment characteristics (e.g., smoothness, compensation, precision, and range of motion), mainly because the games provided a limited means to configure the difficulty level. Augstein et al. also briefly reported that therapists were not satisfied with the preprogrammed difficulty levels of games and desired to have more flexible control over game parameters [7]. Similarly, Smeddinck et al. found that therapists wanted to identify game parameters that can be used to adjust the difficulty level of rehabilitation games but, at the same time, wanted the games to adjust the values automatically [127]. These suggest a need for highly configurable game systems that can provide flexibility for therapists’ to enable personalized therapy programs. On the other hand, the increased complexity of game operation would demand extensive training for therapists to become competent in moderating game-assisted therapy sessions.

**Needs for Training on Game-Assisted Therapy.** Our study provides empirical evidence that therapists heavily rely on their own lived experience in moderating game-assisted therapy and demand for proper education or training. In conventional therapy, it has been well recognized that therapists’ competency in multi-faceted skills—which include but not limited to therapeutic knowledge, and physical and social intervention skills—is an important factor to enable quality therapy [46]. It has also been emphasized that such competency affects the establishment of strong rapport with patients and can be achieved via continued offline and online education and training [32, 89, 143]. For another example in robot-assisted therapy that involves much more complex assistive tools, manufacturers (e.g., Hocoma, one of the most active manufacturer in the rehabilitation robot industry) often provide a series of extensive in-person training sessions [48], as well as online training materials [49], to help therapists deliver personalized therapy using their technological solutions. In sum, our findings support that it may be necessary to design game systems that can provide flexible configurations to enable personalized therapy and to provide carefully designed training sessions for therapists to learn how to operate game platforms effectively.

### 5.2 Customized Approaches for Patients with Different Engagement Patterns

**Deliberate Adjustment of Entertainment Features for Misdirected Gamers.** The first patient group—*misdirected gamers*—strongly pursue the entertainment values of rehabilitation games rather than focusing on the therapeutic values (i.e., the actual goal of game-assisted therapy). During game play, these patients insist on playing the game that they strongly prefer, which usually involve therapeutically less meaningful movements, and/or recruit severe compensatory behaviors. In the literature, Lange et al. similarly argued that patients may pay less attention to their movement quality as a result of gamification of rehabilitation exercises [75]. The effect of such shifted focus may lead patients to recruit significant, therapeutically-undesirable compensatory movements, as we observed in our study. However, most studies on serious games for rehabilitation have focused solely on investigating how to enhance patients’ engagement to games [84]. For example, researchers have applied the Flow Theory in designing rehabilitation games such that patients can focus more on (or improve attention to) game play [17, 86]. The Flow Theory asserts that, in order for a player to experience the fun (in our context, engagement), the difficulty level of games should be appropriately adjusted to balance between the player’s ability and the amount of challenge that the player has to encounter during the game play [25]. For another example, previous studies on serious games in healthy elderly individuals reported that participants could be more engaged in exercises when they played challenging games and attained the feeling of achievement [27, 38]. However, our study suggests that such an approach might not be applicable...
to *misdirected gamers* who are already excessively immersed in game play and consequently depreciate the therapeutic values. We believe that this is associated with the unique functional characteristics in stroke survivors that (1) the impairments are prominent only in some parts of the body (e.g., stroke-affected limb) and (2) it often requires great efforts (or even with pain) to generate game-required movements using the affected limb that they are aiming to rehabilitate. Consequently, when *misdirected gamers* are challenged during game play to generate a movement with the stroke-affected limb, they choose rather an easy solution to address the challenges—i.e., compensating the movements using other less-affected body parts such as swinging the trunk to reach to a target—so that they can maintain their entertainment values. Therefore, it may be necessary to introduce serious games to stroke survivors with care based on their propensity for games and/or design games that can opportunistically adjust the entertainment features to enhance their attention to the therapeutically important factors (see Section 5.3 for further details).

**Strong Rapport and Supervision for Attentive Cooperators.** The second patient group represents *attentive cooperators* who actively engage in therapeutic exercises and follow the lead of therapists in game-assisted therapy. These patients are often in their early stages of recovery, as discussed in Section 4.1. Some of the observed traits of these patients concur with what has been reported in previous studies. For instance, Yu et al. reported that, in conventional therapy, patients would better adhere to rehabilitation in their early recovery phase when they are eager to recover and return home [149]. Furthermore, our results also showed that *attentive cooperators* establish a strong rapport with their therapists, and potentially diminished rapport may lead to patients’ poor adherence to therapists’ instruction and game-assisted therapy. In conventional non-game-assisted rehabilitation process, the rapport between therapists and patients have been recognized as an important factor that significantly affects patients’ compliance with treatment [123]. Our findings support that serious games are another form of therapeutic activities, and hence, the strong rapport between the patient and therapist is as important as in conventional therapy.

It is noteworthy that therapists strongly believe that they should have the ownership to moderate game-assisted therapy (e.g., selecting what games to play or adjusting difficulty level) for most patients regardless of their engagement patterns to maximize therapeutic benefits. Therapists occasionally asked some *attentive cooperators* to choose a game but never the difficulty level. Contrary to our findings, previous studies on serious games in healthy elderly individuals reported that participants felt improved ownership when selecting games to play from a variety of choices [37, 38], which contributed to enhancing their adherence level [105, 118]. We believe this discrepancy is again related to the unique functional characteristics in stroke patients that they—including *attentive cooperators*—show a strong propensity to adhere to the games they are familiar with or functionally easy to play, which is therapeutically counter-productive.

**Prehabilitation Before Game-Assisted Upper-limb Rehabilitation for Inattentive Bystanders.** The third patient group (i.e., *inattentive bystanders*) includes those who did not engage in game-assisted therapy due to either their low motivation for rehabilitation in general (i.e., *patient sub-type A*) or their poor cognitive function (i.e., *patient sub-type B*). Previous studies suggest that many patients with chronic impairments have diminished confidence in their potential recovery of the lost motor function and, as a result, show poor adherence to the prescribed rehabilitation regimens [24]. Furthermore, patients’ low motivation and lack of belief in potential recovery may be related to the symptoms of depression as it has been reported that patients with severe depressive symptoms or a history of diagnosed depression would poorly adhere to therapies and achieve a lower recovery rate [41]. As our findings suggest, game-assisted motor rehabilitation may not appeal to patients when their motivation for rehabilitation is low (i.e., *patient sub-type A*). Hence, for these patients, we believe it is appropriate to leverage other therapeutic methodologies (e.g.,
music therapy [87, 95, 111, 133] or games integrated with music therapy [36, 141]) to treat their depressive and emotional symptoms before considering the use of serious games for motor rehabilitation (e.g., Rappael Smart Board used in this study). Furthermore, patients’ poor cognition can challenge them to stay engaged in therapy and pay attention to executing therapeutically meaningful exercise movements [26, 65, 98]. Hence, for patient sub-type B, serious games for motor rehabilitation may not be an effective solution, and alternate rehabilitation methodologies based on simpler stimulation/feedback modalities (e.g., auditory [42, 47, 122] or vibrotactile feedback [62, 63]) could be more effective. These patients may be introduced to game-assisted therapy if their cognitive function improves after cognitive rehabilitation therapy.

**Educating on Added Value of Game-Assisted Therapy for Old-Fashioned Enthusiasts.** The last patient group includes old-fashioned enthusiasts who prefer conventional therapy over game-assisted therapy. It is noteworthy that these patients prefer non-game-assisted, conventional therapy, and thus, game-assisted therapy may not be necessary. Perhaps, the use of games could be considered, especially for sub-type C patients, only when their motivation and engagement level becomes deteriorated after extensive exposure to conventional therapy. Furthermore, more individualized approaches could be taken to appeal to these patients based on their preference or preconception of therapy and games. Patients in sub-type D perceive games as childish and not serious (or therapeutic) enough. The traits of these patients have been similarly witnessed in prior studies. For instance, Pickrell et al. reported that some stroke patients in their observational study thought that games were only suitable for children [106]. Lewis and Rosie, in their review paper, suggested that stroke patients perceived games as supplements to conventional rehabilitation therapies and believed that game-assisted therapy would provide limited therapeutic benefits [81]. It is possible that patient sub-type D may maintain their negative attitudes toward rehabilitation games even when their motivation level for conventional therapy is deteriorated. Perhaps, the negative attitudes of these patients toward game-assisted therapy could be understood and approached from the perspective of the Trans-Theoretical Model (TTM), which has been applied to conceptualize patients’ health-related behaviors and their changes [110]. The TTM explains that those who are un- or under-informed about the expected benefits of new behaviors may not attempt to adopt such behaviors (i.e., a precontemplation stage). Hence, one possible way to help people change their health-related behaviors includes improving their awareness of the consequences of the current and new behavior [110]. To apply the TTM to our study, we may explicitly inform and educate stroke patients about the purpose and potential benefits of rehabilitation games. We believe such an explicit education could help these patients appreciate the added values of game-assisted therapies, which may lead them to the contemplation and later stages. Yet another potential approach to introduce game-assisted therapy to this type of patients is to design the games that appear less cartoonish (or childish) and incorporate the aspects of conventional therapeutic apparatus, which we will discuss in more detail in Section 5.3.

**Identifying Patient Types Prior to Prescribing Game-Assisted Therapy.** As discussed above, game-assisted rehabilitation may lead to greater therapeutic benefits when games are carefully applied to patients with adequate motor and cognitive abilities at appropriate times. Hence, assessing patients’ anticipated engagement patterns prior to prescribing game-assisted therapy could help clinicians identify a group of patients who are likely to benefit from the intervention. Unfortunately, to the best of our knowledge, there are no studies to date that have specifically investigated characteristics and predictors of stroke patients’ engagement patterns in game-assisted therapy. On the other hand, there has been a large volume of research to understand the potential predictors of patients’ participation in conventional, non-game-assisted rehabilitation therapies. For example, patients’ perceived importance and understanding of the necessity of rehabilitation for functional
recovery [33, 69, 85], impairments in cognition and audio/visual sensation [70, 79], and depression and/or emotional status [108, 124] have been identified as factors that could significantly affect patients’ motivation, engagement, and adherence to therapeutic regimens, which closely agree with the findings reported herein. Independently, the predictors that affect the engagement level of players in games—often associated with excessive engagement and addiction issues—have been actively investigated. Factors such as gender, age, and psychological (e.g., attention, mood, and anxiety) and psychopathological conditions (e.g., attention-deficit/hyperactivity disorder and depression) have shown as potential predictors for pursuing excessive engagement in games [43, 55, 145]. We believe that these predictors, along with the traits we have observed in our study (e.g., chronicity, motor impairment level, and prior exposure to games), could be similarly applied to identify stroke patients’ perception and inclination to therapeutic and entertainment values, and thus their engagement patterns in game-assisted therapy.

If predictors for one’s engagement patterns to game-assisted therapy could be identified, we can optimize clinical resources towards the patient group that will most likely cooperate with their therapists and benefit from the therapy. For instance, stroke patients may be screened based on their cognitive and motor function (e.g., using the Mini Mental State Examination [35] and Wolf Motor Function Test [146], respectively) and depression level (using the Hospital Anxiety and Depression Scale [150]), which are often periodically administered in rehabilitation hospitals. Then, based on the identified predictors, patients could be interviewed to further understand their potential attitude towards game-assisted rehabilitation therapy. The selected patients may be provided with a trial session to observe patients’ reactions, based on which patients could be included in or excluded from the game-assisted therapy program. Therefore, the identification of predictors and in-depth evaluation of screening mechanisms for patients’ future engagement patterns remains as important future work.

5.3 Design Implications

Building on the findings and discussions reported in this work, we offer a series of design implications aiming to (1) improve the translation of game-assisted therapy to patients who were not able to engage in or benefit from game-assisted therapy and (2) support therapists to better personalize games for individual patients.

A Modularized Game Architecture Supporting Flexible Configuration. Unlike the traditional videogame design that pursues the maximum level of engagement of players to the content, rehabilitation games aim to provide the users with a balanced experience between engagement and therapeutic relevance (e.g., quality of movement). Also, the design of rehabilitation games should consider different levels of players’ cognitive abilities and preferences for game styles. To address these challenges, we suggest a modularized and easily reconfigurable game architecture, consisting of the following components: (1) physical movements for rehabilitation, (2) game mechanics and difficulty level, and (3) visual appearance.

In this architecture, the mapping between physical movements and their manifestation in the games can be easily altered or remapped depending on the context of rehabilitation. The game system used in this study (i.e., Rapael Smart Board) only allowed pre-determined exercise movements to play a specific game. For example, in the shoot ‘em up style game or pet-feeding game (Figure 1(b)), patients must perform reaching movements to control the jet fighter or the pet foods to play the game, respectively. In the dough-mixing game (Figure 1(c)), patients had to perform joint coordination movements (i.e., making circular movements) to play the game. A game system allowing therapists to mix and match between the required physical movements and game contents (e.g., making circular movements to control the jet fighters) will provide patients with more
personalized gaming experience while achieving the rehabilitation goals, especially for patients with strong preferences for a certain set of games (e.g., misdirected gamers). In designing this flexible architecture, developers may take advantage of previous studies that have investigated the mapping and balancing techniques between heterogeneous input modalities (i.e., different exercise movements) [2, 39, 102, 103, 148]. Furthermore, the rehabilitation game system’s interface (e.g., controllers) should be designed, such that patients can practice different exercise movements while voluntarily suppressing their compensatory behaviors. As Brokaw et al. discussed, the end-effector style controller mechanism that takes only the horizontal position of patients’ hand as a game input (i.e., the controller of Smart Board) cannot effectively discourage stroke patients from using compensatory behavior unless therapists’ supervision is provided [19]. On the other hand, Alankus et al. demonstrated that games could be designed to take trunk movements as a game input to induce less trunk-related compensatory movements from patients [2]. Similarly, stroke patients who undesirably recruit shoulder or elbow movements can be addressed by taking the compensating joint as a game input. Such an implementation may help reshape patients’ behaviors in game play by allowing them to receive positive feedback (e.g., game points or rewards) only when they perform therapeutically meaningful movements. Moreover, for misdirected gamers, games can be configured to deliberately adjust the patients’ enjoyment of playing games (i.e., entertainment values) to enhance their attention to the quality of their exercise movements (i.e., therapeutic values). This relates to the concept of Dynamic Difficulty Adjustments (DDAs) in video game design [51, 82], where the technique has been mainly used to keep the game player in the maximum band of enjoyment (i.e., the flow channel) [51]. For misdirected gamers, in contrast, a similar technique may be leveraged to opportunistically drive the patients away from the flow channel to maintain the balance between the therapeutic vs. entertainment values.

We envision that reconfigurable visual appearance can help enhance the participation of some patients who were not initially interested in game-assisted therapy. Our findings demonstrate that patients can react differently to the same cartoon-like graphics (e.g., inattentive bystanders, patient sub-type B vs. old-fashioned enthusiasts, patient sub-type D in Figure 2). Patient sub-type B of inattentive bystanders, who often have a severe cognitive impairment, have difficulty processing realistic graphics and consequently become disengaged. On the other hand, patient sub-type D in old-fashioned enthusiasts perceive rehabilitation games childish and not therapeutic enough. The reconfigurable visual settings can accommodate these patients of different propensity and cognitive level. Graphical representation can be adjusted to look uncomplicated (e.g., just a simple 2D rectangular object rather than a jet fighter) to help patient sub-type B of inattentive bystanders better comprehend and engage in therapy. On the contrary, the appearance can be adjusted to look like real-world therapeutic apparatus, which can provide old-fashioned enthusiasts an impression that rehabilitation games are not for entertainment but for serious therapeutic purposes. Furthermore, we suggest providing a more fine-grained way to adjust game difficulty level (rather than only three difficulty levels in Rapael Smart Board) to accommodate cognitively impaired patients.

**Serious Games that can Monitor Patients’ Motor, Affective, and Psychological Conditions.** Our findings showed one of the most important roles of therapists—or perhaps the most important role according to T2—is to supervise and ensure the quality of exercise movements that patients perform during therapy sessions. In addition, we observed that therapists continuously monitor patients’ affective (e.g., pain and fatigue) and psychological (e.g., anxiety and boredom) conditions and actively intervene such that patients could maintain or further enhance their engagement to game-assisted therapy (see Cheerleading the Therapy in Section 4.2). Game systems can be implemented to automatically assess patients’ quality of exercise movements, and their affective and psychological conditions during game play, for example, by combining vision or
wearable technologies with Artificial Intelligence (AI) and Machine Learning (ML) algorithms. Then, such systems could continuously adjust the game configurations to help remind patients about the importance of appropriate movement execution while closely monitoring patients’ engagement level. Such an increased role of AI-enabled game systems can reduce some of the therapists’ overwhelming roles to orchestrate the entire therapy sessions. Indeed, a large number of recent studies have investigated to leverage camera sensors [6, 8, 29, 138], wearable inertial sensors [59, 60, 92, 99, 115, 117, 139], and wearable physiological sensors [68] to estimate movement quality, affective state, and psychological condition of patients undergoing rehabilitation.

The measured information regarding the quality of exercise movements, and patients’ affective and psychological states can be delivered to patients and therapists in different ways. For example, visual or auditory feedback can be used to remind patients regarding the quality of the performed movements [47, 126, 138]. The game system can also provide mechanical feedback (e.g., interrupting the movement of the handle when patients show undesirable behavior) [134] or software feedback (e.g., increasing game points only when movements are performed with the appropriate quality or punishing when undesirable behaviors are observed) [2]. It is noteworthy that providing feedback regarding the movement quality or integrating the quality information as part of the game play will increase the therapeutic values of game-assisted therapy but, at the same time, will act as a factor that somewhat disengages patients from their entertainment values (as T2 explicitly stated in Section 4.2). Monitoring patients’ affective and psychological states could then help therapists to evaluate patients’ enjoyment and engagement to the prescribed games and personalize the program to address the patients’ specific needs. As we reported in Section 4, pain and boredom are the major factors that disengage patients from rehabilitation therapies. It remains an important research problem to find the optimal balance between the therapeutic and engagement values (e.g., an application of DDAs as we discussed previously).

Accurate and reliable assessment of patients’ conditions and their rehabilitation performance can be used to promote communication between therapists and patients, enhance rapport, and support shared decision-making, which in turn can contribute to maximizing therapeutic gain. For example, previous studies demonstrated that having an opportunity to review the patient’s movement data together with the patient and therapist can promote extensive conversation and shared decision-making [1, 90, 91, 107] and that patients experiencing chronic pain desire to communicate with therapists about their pain [10, 12]. Prior studies also acknowledged that such a conversation could help establish stronger rapport between therapists and patients, increase the level of patients’ engagement in therapy [11, 97, 104], and help therapists design patient-centered rehabilitation programs [30]. Indeed, according to our findings, therapists felt that it was easier to build rapport by conversing with patients about their game play (see Therapists’ Roles in Game-Assisted and Conventional Therapies in Section 5.1) and stated that stronger rapport could motivate patients to exert more efforts during exercises (see Attentive Cooperators in Section 4.1). However, our study also showed that therapists did not use or share with patients the game-generated assessment of patients’ performance because therapists found the assessments inaccurate and unreliable (see Challenges to Prepare the Game System in Section 4.3). We believe this was a missed opportunity to build stronger rapport between therapists and patients. It remains an important future work to investigate the impacts of data sharing on the effectiveness of game-assisted rehabilitation.

A Dedicated User Interface for Therapists Enabling Efficient Control. To enable therapists to orchestrate the aforementioned game components and thereby keeping the balance between the therapeutic and engagement values during run-time, we suggest a real-time user interface that allows therapists to configure game settings (e.g., entertainment factors) in a subtle and unnoticeable manner to induce patients to perform therapeutically appropriate movements. It may
include a miniaturized hand-held or foot-pedal controller to minimize the patients’ sense of being controlled by the therapists. Our study findings demonstrate that strongly opinionated patients become disengaged from game-assisted therapy when the patients’ preference and therapists’ suggestion conflict with one another. It puts therapists into a dilemma. That is, if they explicitly enforce therapeutically desirable execution of exercise movements to strongly opinionated patients, it is likely to decrease their motivation to participate in game-assisted therapy (see misdirected gamers in Section 4.1). This finding is consistent with a previous study reported that explicit and transparent balancing diminishes self-esteem and perceived relatedness, whereas hidden and implicit balancing improves self-esteem without significantly affecting the outcomes of games [39].

Our suggested user interface can be used in the following ways. When a patient tends to develop compensatory behaviors during gameplay, the therapist could configure the game to decrease the range of motion in the game or the speed of the game pace using a small remote controller—which should be hardly noticeable from the patient’s sight—so that the patient can perform movements without severe compensatory behavior. When patients develop fatigue or pain, therapists may make games less challenging or even pause the games, such that game-induced injury could be avoided [136].

We also emphasize that the overall usability of the game system for therapists should not be overlooked. As our study illustrates, therapists control games entirely on behalf of patients (see Designing the Therapy in Section 4.2) using a mouse on the edge of a table, on the game controller itself, or on their lap (see Challenges to Prepare the Game System in Section 4.3). On the other hand, in order to physically interact with patients (see Correcting Inappropriate Movements in Section 4.2), therapists often sit next to or behind their patients. In other words, therapists need to continuously re-position themselves to control the game platform and interact with patients during therapy sessions. Hence, a dedicated, portable user interface is needed for therapists to interact with games and moderate game-assisted therapy more efficiently.

In the long term, we believe that many aspects of the aforementioned roles of therapists could be ultimately assisted by AI components, such that therapists’ roles to control and fine-tune game parameters could be reduced. For instance, our findings show that therapists would adjust patients’ active range of motion that was measured from the calibration process to induce appropriately challenging exercise movements (see Challenges in Run-Time in Section 4.3). Patients’ movements can be monitored using a variety of sensors, as explained in the previous subsection, and the patterns that therapists adjust patients’ range of motion can be learned by AI and ML algorithms, based on which the reaching targets can be automatically adjusted to balance the player’s ability and the amount of challenge [57]. This will enable therapists to focus more on clinically important aspects of game-assisted therapy, such as verbal and physical assistance, to induce more clinically appropriate exercise movements [4].

6 LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Cultural Context of the Study Site. Similar to other studies, this work is limited to our specific case study and sample population. This study involved a relatively small number of study participants at a single site in South Korea, and thus, there may exist country- or hospital-specific cultural effects on patients’ engagement and therapists’ strategies in game-assisted therapy. For instance, in Korea, due to the influence of Confucianism, young individuals are expected to interact with the elderly with extra courtesy and respect [101]. Furthermore, there is evidence that patients in Korea tend to show poor compliance to instructions given by less authoritative figures [66]. Therefore, elderly patient participants (69 ± 12 years old) in our study might have perceived the young therapists (25 ± 2 years old) less authoritative, which may have affected patients’ compliance to the therapists’ moderation of game-assisted therapy. More specifically, we believe such
a culture may have influenced misdirected gamers when therapists strove to depreciate their entertainment values and patient sub-type D of old-fashioned enthusiasts when they were first introduced to game-assisted therapy.

On the other hand, the popularity of video games (also referred to as e-sports) in the Korean population [128] could have influenced the patients to establish positive attitudes towards accepting game-assisted rehabilitation in comparison to other cultures. However, we believe such a culture had minimal impacts on our findings, especially related to the patient engagement patterns because most of the patients were elderly (69 ± 12 years of age) and did not have extensive prior experience with video games. This was evidenced in Section 4.1, where T4 stated that “You know, these patients have never played video games before.” Despite these unique cultural factors in Korea, we believe the findings reported herein could be generalized to other hospitals and countries, because (1) the study site (i.e., HRH) was operating therapeutic programs that were similarly adopted in other modern hospitals (see Section 3.1 for details) and (2) the patients’ engagement patterns were identified mostly based on their pathological characteristics (e.g., the level of cognitive and motor function, the level of depressive symptoms) that are less influenced by the cultural factors. Furthermore, a previous study that compared culture-specific factors contributing to patient satisfaction in rehabilitation care—a clinical outcome measure that reflects patients’ comprehensive experience with rehabilitation—also supports that patients from Korea share similar values (i.e., the importance of effective communication and respect from therapists) [53] with other countries in Europe, North America, and Australia [52, 54].

**Game-Assisted Rehabilitation System: Repael Smart Board.** The current study was conducted using a single game-assisted rehabilitation solution that was specifically designed for gross upper-limb rehabilitation. Hence, the reported results should be taken with care when translating to other upper-limb rehabilitation tools or solutions that focus on different impairments such as fine-hand, gait, and cognitive rehabilitation. However, as discussed in Section 3.4, the game design and controller mechanism of the Smart Board system share similar characteristics with other widely accepted upper-limb rehabilitation solutions, such as InMotion Arm (Bionik Laboratories Corp., Canada) [71] and Armeo (Hocomo AG, Switzerland) robots [31]. Thus, we believe our findings related to the user interfaces of the Smart Board systems could be applicable to other systems for upper-limb rehabilitation. Furthermore, we believe the key findings (i.e., the existence of different engagement patterns in patients, therapists’ comprehensive roles, and lack of systematic support for therapists) could also be generalized to broader types of game-assisted rehabilitation tools targeting different impairments.

**Therapists’ Perspective vs. Patients’ Perspective.** The current study mainly focuses on the lived experiences of therapists in their perspectives without encompassing the thoughts and experience of patients. This approach, in turn, has yielded a number of important findings in this work, such as different patient engagement patterns that therapists had experienced, the imperative roles of therapists to moderate the therapy, and the lack of support for therapists to enable patient-centered care, which have not yet been thoroughly investigated in the field. Although we specifically designed the study in two stages (i.e., video analysis followed by the interviews) in order to minimize any potential discrepancies between therapists’ narration and the actual interaction dynamics, there is a possibility that the reported findings are affected by therapists’ subjective biases. The thoughts and experiences by patients, especially those who exhibit negative attitudes to rehabilitation games and game-assisted therapies, were not analyzed in the patients’ viewpoint. Investigating patients’ perspectives (e.g., perception of their own disability and its relation to engagement patterns [109]) can provide a more balanced understanding of their engagement patterns in game-assisted therapy sessions and remains as important future work.
Potential Variation in Therapists’ Intervention Strategies. While we focused on patients’ engagement patterns in this study, therapists may similarly exhibit some variability in their intervention strategies and engagement patterns during game-assisted therapy. However, in this study, we observed in the video data that such variability is minimal, and therapists leveraged similar intervention strategies, primarily because they had regular meetings with their peer therapists and shared their experience of moderating game-assisted therapy, as we described in Section 3.1. However, future research may reveal therapists’ different therapy styles that are specific to their personal traits and education, particularly in hospitals where therapists have fewer opportunities to interact with each other.

Additional Research Opportunities. Our study sheds light on a number of other important future research opportunities in the development of rehabilitation games. For example, an interesting future work will be to develop and investigate the clinical effectiveness of an interactive mechanism that allows clinicians to adjust the entertainment features of serious games to preserve therapeutically important factors (e.g., quality of movement) when patients start to ignore therapeutic goals and excessively pursue entertainment values. Furthermore, it remains as important future work to investigate how the engagement patterns that we summarized in Figure 2 could evolve over time (e.g., in several months) and how a specific game mechanics (e.g., a certain type of or the quality of patients’ movements to interact with the game state) could support or hinder patient engagement. Such enhanced understandings will provide insights into new design implications that go beyond the foundational work presented in this article.

7 CONCLUSION
This study reports our inquiry into the interaction dynamics among patients, therapists, and games during routine game-assisted therapy in the actual clinical setting. Our study contributes to the field by presenting stroke patients’ different engagement patterns that are manifested and therapists’ roles in administrating personalized game-assisted therapy sessions, as well as practical challenges they face during therapy. Based upon clarified and enhanced understanding of the interaction dynamics, we discussed potential research and development directions to enhance/maintain patients’ engagement in a therapeutically more meaningful way, develop dedicated user interfaces and training to better support therapists’ comprehensive roles.

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