Towards Efficacy-Centered Game Design Patterns For Brain Injury Rehabilitation: A Data-Driven Approach

Jinghui Cheng, Cynthia Putnam, Doris C. Rusch
College of Computing and Digital Media, DePaul University
243 S. Wabash, Chicago, IL, 60604
{jcheng13, cputnam, drusch1}@cdm.depaul.edu

ABSTRACT

Games are often used in brain injury (BI) therapy sessions to help motivate patients to engage in rehabilitation activities. In this paper, we explore game design patterns as a mechanism to help game designers understand needs in BI therapy. Design patterns, originating from the work of Christopher Alexander, aim to provide a common language to support the creative work of designers by documenting solutions that have successful addressed recurring design problems. Through analyzing data we gathered on the use of commercial games in BI therapy, we generated a list of 14 'efficacy-centered game design patterns' that focused on game design considerations when addressing therapeutic goals in BI rehabilitation. We argue that our patterns can serve as a common language to support the design of BI rehabilitation games; additionally, our data-driven approach sets up a paradigm for generating game design patterns in related areas.

Categories and Subject Descriptors

K.4.2 [**Computers and Society**]: Social Issues – *handicapped persons/special needs*; K.8.0 [**Personal Computing**]: General – *games*

General Terms

Documentation, Design, Human Factors.

Keywords

Brain injury; gaming therapy; game design; game design patterns.

1. INTRODUCTION

The aim of this work is to support the creation of therapy-centered games for brain injury rehabilitation by empowering game designers. Brain injury (BI) is a leading cause of long-term disability in many societies [32]. Approximately 6.4 million children and adults in the US live with a lifelong disability as a result of a BI [35]. BIs originate from diverse causes, including external traumatic events such as car accidents and firearms, loss of oxygen to the brain, and cerebral vascular accidents (i.e. stroke) [1, 38]. People who have sustained a BI can exhibit a wide range of impairments affecting both gross and fine motor coordination; BIs can also affect cognitive abilities including problem solving, memory, learning, and speech [16, 38]. Due to the diverse causes and effects associated with BIs, rehabilitation treatments also vary widely and need to be customized by therapists; many treatments involve repetitive activities to reinforce learning. Clinical experience and cases cited in the literature have identified that it can be challenging to motivate patients to engage in repetitive activities needed for BI rehabilitation [5, 15]. As a result, many therapists use video games and gameful activities in their therapy sessions to help engage their patients.

Therapists use varied combinations of commercial off-the-shelf (COTS) games designed for the general public and games that are specifically designed for BI therapy [4]; choices of game use are influenced by budget and availability. While some COTS games were identified as both motivating for patients to engage in rehabilitation activities and effective at addressing therapeutic goals [31, 41], research has indicated that COTS games are often too fast-paced and too challenging for BI patients [36]. Further, some games provide negative feedback that could be inappropriate for people who have had a BI [25]. To mitigate the limitations of COTS games, researchers and practitioners have created games that are designed specifically for BI rehabilitation [9, 11]; these have included games run on specialized platforms (e.g. virtual reality systems [37]) and games that leverage commercially available hardware (e.g. Kinect sensors [14, 24], and Wii remotes [2]).

Efforts to create games for BI rehabilitation supports that therapy-centered game design is an important area for the future of BI therapies. However, most of the current games/systems are either experimental or if commercial (e.g. Jintronix [21] and MIRA [30]) have not reached a high level of diffusion. A common critique of games designed to address BI rehabilitation was that they are not engaging [8]; one important reason cited for a lack of engagement was the oft-limited communication and mutual understanding among game designers and subjective matter experts (e.g., therapists) when creating these games [8, 40]. Design patterns, originating from the work of Christopher Alexander, aim to provide a common language to support the creative work of designers by documenting successful solutions that have addressed recurring design problems [3]. In the field of serious games (i.e. games designed to support an external purpose [8]), game design patterns were advocated as a communication tool that supports the collaboration among team members who have diverse backgrounds [17, 23, 28].

Much of the previous work that has explored patterns in serious game design focused on educational games (see section 1.1.3 for details); however in our literature review we found that only a few researchers have investigated design patterns for rehabilitation games [17] and we were unable to find work specifically focusing on game design patterns that address efficacy issues for BI therapy-centered games. We argue that investigating patterns in games for rehabilitation is beneficial for designers who are interested in rehabilitation games for several reasons. First, game design patterns have the capacity to capture the qualitative (and usually heterogeneous) information about BI rehabilitation needs in a fixed structure to facilitate expansion of game design knowledge. Second, patterns have the ability to distill abstract game design knowledge from a large amount of data about how well existing games worked in therapy into a set of coherent and tangible exemplars. Finally, patterns as a common language can serve as a valuable tool to facilitate effective communication and mutual understanding among game designers and therapists. As such, game design patterns can play an important role in capturing design knowledge in games used in therapies and further inform and promote therapy-centered game design.

In this paper, we address a gap in literature by investigating design patterns that focus on game design considerations when addressing therapeutic goals in BI rehabilitation; we call them 'efficacy-centered game design patterns'. In particular, we introduce a data-driven approach of pattern generation; i.e. we focus on generating game design patterns through analysis of the data we gathered about the efficacy of COTS games used in BI therapy.

1.1 Related Work

This study builds upon several areas of related work, including: (1) the use of commercial off-the-shelf (COTS) games for BI rehabilitation, (2) investigation of games that are specifically designed for BI therapy, and (3) game design patterns.

1.1.1 COTS Games for BI Rehabilitation

Work that has examined COTS games presumed that these games were designed to be engaging and, if proved effective in addressing BI rehabilitation goals, they would serve as a promising candidate to achieve a balance between player engagement and rehabilitation efficacy. Researchers have investigated COTS games for BI rehabilitation on several gaming platforms, including Nintendo Wii [10, 29], Sony Play Station [41], Microsoft Xbox [31], and web-based games [42]. For example, Paavola et al. (2013) conducted a case study using Kinect Adventures on Xbox 360 for ten sessions over a month with a 29-year-old patient sustained a BI. Over the intervention, the participant showed improvements in movement performance and physical clinical outcomes including balance and gait [31]. Zickefoose et al. (2013) investigated the efficacy of Lumosity (a web-based brain training program, also available on tablets [18]) for cognitive improvement in four participants who have had a BI. They found that while participants made significant improvements through the intervention, there was limited evidence showing that cognitive skills gained were generalizable to tasks outside of the game [42]. While not focusing directly on game design, the lessons learned in the use of COTS games can greatly inform games created specifically for BI rehabilitation.

While having obvious advantages such as low cost and scalability, COTS games have several limitations for use in BI rehabilitation. For example, COTS games are usually not feasible for low functioning patients [36] and some games provide negative feedback that could be inappropriate for people who have had a BI [25]. As a result, therapists use COTS games only with a small portion of their patients; i.e., those who demonstrate higher physical and cognitive abilities [34]. In addition, research has supported the need to include adjustable features in rehabilitation games in order to accommodate the wide-ranging causes, effects and recovery paths associated with BIs [2]; COTS games usually do not include such adjustable features.

1.1.2 Creating Games for BI Rehabilitation

To mitigate the limitations of COTS games, researchers and practitioners have created games that are designed specifically for BI rehabilitation. Much of the early work focused on games that ran on specialized platforms (e.g. virtual reality systems [37]) that were usually costly and thus suffered from limited scalability to general therapeutic practices. Along with the development of motion capture technologies and the availability of motion-based game consoles (e.g. Nintendo Wii and Xbox Kinect) and portable devices (e.g. iPad), research in this area has more recently shifted towards methods that create customized games leveraging commercially available hardware; many focused on games with adjustable parameters (e.g. [2]). Examples leveraging commercial hardware to create custom games include methods using low-cost webcams [9], Kinect sensors [14, 24], and Wii remotes [2]. For example, Burke et al. (2009) developed a series of webcam-based motion-games for stroke rehabilitation; their evaluation indicated that these games had the potential to support in-home therapy [9].

Researchers have also generated design guidelines for BI rehabilitation games aimed at binding fun factors and the effectiveness of the games. For example, Flores et al. (2008) generated a list of design criteria for stroke rehabilitation games that also focused on entertaining elderly people [12]. In addition, many researchers in this area have argued that a successful collaboration between subject matter experts and game creatives is crucial for creating successful games that are both engaging and contain the appropriate therapeutic contents [8, 12].

1.1.3 Game Design Patterns

Based on the work of Christopher Alexander, design patterns are a collection of solutions that solve recurring problems in corresponding contexts [3]. After its introduction in architecture, the concept of design patterns has been adopted in many fields, including software engineering [13] and interaction design [7].

Björk and Holopainen (2004) completed the most comprehensive work applying the concept of design pattern in the field of game design [6]. Through an examination of common game mechanics, existing games, and game design methods, they generated a set of over 200 game design patterns organized in 11 broad categories. Each of their patterns included (1) a name, (2) a core definition, (3) a description of how it is used in current games, (4) a specification of designers' choices applying the pattern, (5) the resulting gameplay of the pattern, and (6) its connections to other patterns [6]. As such, their patterns constituted a very comprehensive common language of game design that could arguably be used to analyze and design games.

However, Björk and Holopainen's pattern language has been criticized for not being able to capture some of the important game design factors, such as contextual issues [22] and the expected player experience [26] and behavior [19]. Further, their patterns were not intended to cover design considerations of certain game components (e.g. level design [19]) and game types (e.g. serious games [28]). Recent research has examined game design patterns in the context of shooter games [19], role-playing games (RPG) [39], online social games [27], and mobile casual games [22]. Researchers have also explored how player experiences such as flow [26] and player motivation [27] can be addressed using game design patterns.

In addition, researchers have explored patterns in serious game design; many focused on educational games [20, 23, 28]. We identified two common themes in the literature of this area. First, researchers have used game design patterns to address a common goal/challenge in serious game design: to balance player experience (e.g. engagement) in games and the subject matter that the game addresses. For example, Huynh-Kim-Bang et al. (2010) investigated how game design patterns can help combine fun and learning elements in educational games and developed two sets of design patterns focusing respectively on fun and learning aspects of games [20]. The second theme is that game design patterns were unanimously advocated as a communication tool that supports the collaboration of stakeholders in a game development team. For example, Marne et al. (2012) investigated educational game design patterns as a collaboration space to facilitate communication and mutual understanding among teachers and game designers of educational games [28].

Only a few studies investigated design patterns for rehabilitation games [17]. Goude et al. (2007) mapped game design patterns established by Björk and Holopainen with a taxonomy of common stroke rehabilitation tasks; based on this mapping, they developed a stroke rehabilitation system that includes 20 therapeutic mini-games [17]. While closely related to our work, this work has several limitations: (1) the patterns they used were not specifically addressing therapy-centered game design issues and (2) the mapping they created was based on subjective speculations. In the literature review, we were unable to find work specifically addressing therapy-centered game design patterns. We bridge this gap by creating a common vocabulary that will help game designers focus on the needs of BI rehabilitation. In addition, our creation of this common vocabulary will be driven by data we gathered about game use in BI therapy sessions.

2. METHODS

Our efficacy-centered game design patterns were generated based on the creation and analysis of a dataset that contains game therapy "cases." In this section, we discuss (1) our definition of a game therapy case, (2) methods we used to construct the dataset of the cases, and (3) our data analysis procedure through which we generated the efficacy-centered game design patterns.

2.1 Structure of a Game Therapy Case

A game therapy case in our study describes a particular situation in which a game is used with a patient to address certain therapeutic goals. Each case contains information about (1) variables concerning patient abilities and play preferences, (2) therapy session goals, (3) information about the game used in the therapy session (e.g. mechanics and requirements), and (4) session outcomes (e.g. the game's effectiveness on the therapeutic goals and the level of player enjoyment). See Figure 1 for a summary of the attributes of a case.

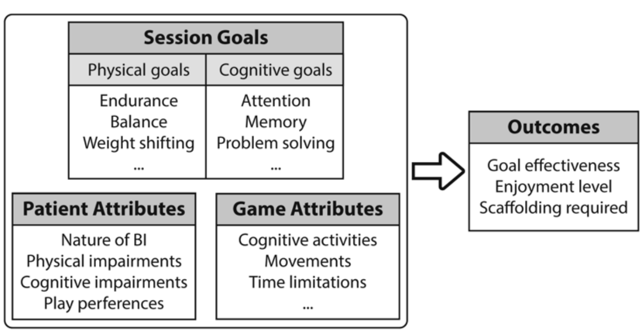

Figure 1. Summary attributes of a case

2.2 Case Collection

To construct a dataset of game therapy cases, we have been working with therapists at Schwab Rehabilitation Hospital in Chicago and Marianjoy Rehabilitation Hospital in Wheaton, Illinois to explore the use of COTS games in BI therapies. We first conducted paper-based diary studies with therapists working with patients who have had a BI to collect initial game therapy cases. We then expanded the case collection methods by including digital diary forms in user feedback questionnaires during beta test sessions of a game recommendation tool that we developed to help therapists choose appropriate COTS games for their patients.

2.2.1 Paper-based Diary Studies

In the paper-based diary studies, therapists were given a notebook containing two-page paper diary forms and were asked to record details about game therapy sessions over two-week periods. We piloted and iterated the diary forms in October 2012 at Schwab; see Figure 2 for the final version of the diary form.

On the first diary page, therapists were asked to record (1) date/time of the session; (2) session details (e.g., if a group session, the number of patients involved); (3) non-identifiable patient details (e.g., age, gender, rehabilitation measures, nature of the BI, assistive devices used, standing endurance, range of motion, fine motor control, command following and sequencing abilities); and (4) the game selections (console, game/mini-game).

On the second diary page, therapists: (1) identified the therapeutic goals (check-marked) for playing each game (the goals that were listed were derived directly from our previous work that included interviews and observations with therapists [33] and the pilot diary study); (2) provided subjective measures of the effectiveness (on a five-point scale) of the game at meeting each goal; (3) rated the level (0-4) of cognitive and physical help needed to play the game; (4) rated patient enjoyment (0-4); (5) assessed appropriate challenge (range from boredom to frustration); and (6) were invited to enter additional comments about the session. We modified the listed goals based on therapist input throughout the diary studies.

We conducted seven periods of two-week diary studies (three at Schwab and four at Marianjoy) from December 2012 to June 2014. In total, 16 therapists participated in the paper-based diary studies, including nine physical therapists, three occupational therapists, two speech-language pathologists, and two recreational therapists. Therapists recorded data for 89 individual patients, ages ranging from 19-95 (M = 53.5); about half (N = 49, 55%) were male. Through the paper-based diary periods, we collected 244 game therapy cases.

2.2.2 Digital Diary Forms

With the initial cases gathered in paper-based diary studies, we created a game recommendation tool to help therapists choose games for their patients. Using this tool, the therapists were able to input patient attributes and session goals and then get a list of games recommended for the input situation based on the cases we collected (see [33] for how we gathered requirements for the tools).

We then conducted beta testing of the prototype system with 29 therapists. During the beta test periods, therapists were asked to make at least three queries per four weeks. After each query, we sent a questionnaire to the therapist who made the query to ask about the therapy session and their experience using the tool. As part of the questionnaire, therapists were asked to complete a digital version of the diary form to record details about game use.

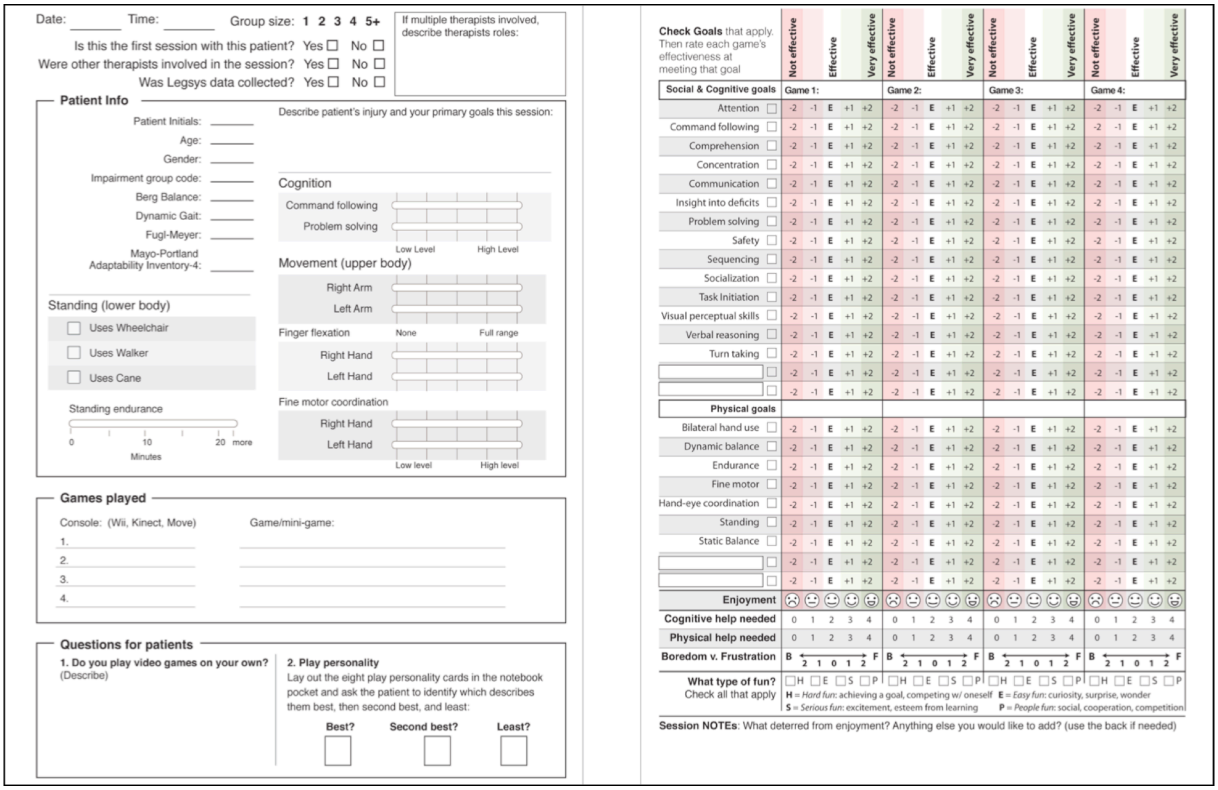

Figure 2. Final version of the diary form

The digital diary form also allowed therapists to (a) add information about new games if they used a game or activity that was not on the recommendation list (which we then added to the case dataset) and (b) state that they did not use any games at all.

As of this writing, we have conducted two periods of four-week beta tests of the prototype between August and November in 2014; a third round is ongoing (initiated on March 2, 2015) and will last for 16 weeks. The 29 participating therapists have made queries that generated 322 new cases via the digital diary forms. In this paper, we focus on the data gathered from both the paper-based and digital diaries.

2.3 Data Analysis and Pattern Generation

Through the case collection methods (paper-based and digital diaries), to date we have created a dataset that contains 566 game therapy cases. We followed five steps to generate the efficacy-centered game design patterns based on these cases; in our approach, we focused on how well the games addressed the intended therapeutic goals.

Step 1: We calculated pairwise Pearson correlation coefficients among the effectiveness of physical and cognitive goals to explore associations among the therapeutic goals. This analysis of association among goals allowed us to identify patterns that address multiple goals and analyze the potential interactions among patterns in later steps.

Step 2: For each goal, we gathered cases addressing the goal and created a list of games that were most frequently used in those cases (i.e. we grouped the games according to the therapeutic goals they address and identified the most frequently used games for each goal). We included games that were used in more than ten cases addressing the goal. If there were less than five games in the list, we also included games used in more than eight cases.

Step 3: For each list of games (i.e. most frequently used games for each goal), we conducted a Kruskal-Wallis test to evaluate differences among the game's average effectiveness score for the particular goal; recall the scores were subjective ratings assessed by therapists. When there was a significant difference, we conducted pairwise Mann-Whitney U tests (with Bonferroni p-value adjustments) to identify the most effective and ineffective games for the goal. We automatically identified a game as effective at addressing a goal if its average effectiveness score on the goal was higher than four (on a scale of 1-5). We labeled a game as ineffective at addressing a goal if the average effectiveness score was statistically significantly lower than than four. These games and their relationships to the goals formed the basis of our pattern generation.

Step 4: One author extracted the common game mechanics and rules in the most effective games (generated from Step 3) for each therapeutic goal and generated the initial list of patterns. All authors then discussed and iterated to an agreement on the pattern list and writing. In particular, we focused on extracting game design elements that contributed to their effectiveness at addressing the targeting goals. When appropriate, we compared the effective and ineffective games for a certain goal to identify important differences. When available, we also incorporated the therapists' comments explaining why they gave the effectiveness score to a game.

Step 5: We finally organized the patterns into categories and analyzed the potential interactions and relationships among the patterns.

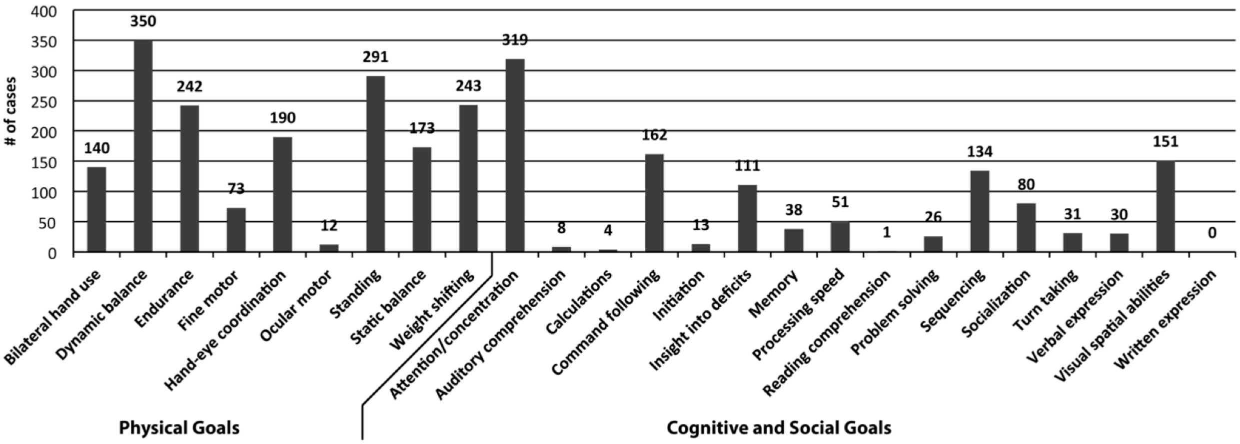

Figure 3. Goal selection frequency

3. DATA ANALYSIS RESULTS

Among the 566 cases we gathered, most (*N* = 528, 93.3%) focused on more than one goal. The most frequently chosen goals were dynamic balance (*N* = 350), attention/concentration (*N* = 319), and standing (*N* = 291); see Figure 3. Pairwise correlation analysis of the effectiveness of goals revealed four groups of session goals that are usually selected together and have similar effectiveness when addressed using the same games:

- Group 1: dynamic balance, endurance, standing
- Group 2: dynamic balance, standing, weight shifting
- Group 3: turn taking, socialization
- Group 4: turn taking, verbal expression

The correlation coefficient matrices among those goals are shown in Table 1; all correlations were statistically significant ($p < 0.05$).

Table 1. Correlation coefficient matrix for selected goals
(Only shows goals with moderate or stronger correlation)

Physical goals			
	Dynamic bal.	Endurance	Standing
Endurance	0.4558*	--	--
Standing	0.4870*	0.4198*	--
Weight shifting	0.5309*	0.2701	0.5662*

Cognitive and social goals		
	Socialization	Turn taking
Turn taking	0.4235*	--
Verbal expression	0.3316	0.4068*

* shows moderate correlation ($r > 0.4$)

In total, 112 games and mini-games were used in the 566 cases. However, game use was skewed towards a small set of games; the top ten most frequently used games appeared in about half of the cases (*N* = 278, 49%); see Figure 4.

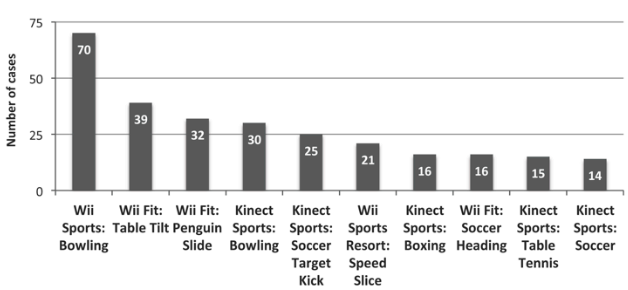

Figure 4. Top ten most frequently used games

Thirteen goals contained enough cases for us to conduct statistical analysis outlined in section 2.3 Step 3. We identified the top effective and ineffective games for those goals; see Table 2 (several goals were combined because they were addressed by the same games).

Table 2. Effective and ineffective games addressing top goals

Goal	Top effective games*	Ineffective games**
Bilateral hand use	Kinect Sports *Table Tennis* *Bowling*	Kinect Sports *Soccer Target Kick*
Dynamic balance	Wii Fit *Penguin Slide* *Table Tilt* Kinect Sports *Soccer Target Kick*	Wii Sports Resort *Speed Slice*
Standing & Endurance	Wii Fit *Table Tilt* *Penguin Slide* Kinect Sports *Table Tennis*	
Weight shifting & Static balance	Wii Fit *Table Tilt* *Penguin Slide*	Kinect Sports *Bowling* Wii Sports *Bowling*
Attention/ Concentration	Wii Fit *Table Tilt* *Soccer Heading* Wii Sports Resort *Speed Slice*	Wii Sports *Bowling*
Hand-eye coordination	Wii Sports Resort *Speed Slice* Kinect Sports *Table Tennis* *Boxing*	Kinect Sports *Bowling* Wii Fit *Penguin Slide*
Insights into deficits	Wii Fit *Table Tilt*	Kinect Sports *Soccer Target Kick* Wii Sports *Bowling*
Sequencing	Wii Sports *Bowling*	
Socialization & Turn taking	Wii Sports *Bowling* Family Feud	
Visual spatial abilities	Wii Fit *Table Tilt*	

	Soccer Heading
Kinect Sports	
	Soccer Target Kick

* Top games whose average effectiveness score was higher than four (on a scale of 1-5).

** Games whose average effectiveness score was statistically significantly different to at least one effective game ($p < 0.05$)

4. PATTERNS

Through the data analysis, we created a pattern library that contained 14 efficacy-centered game design patterns for BI therapy. In this section, we describe our patterns, explore their relationships, and discuss how the patterns can be used in BI therapy-centered game design.

4.1 Overview of Patterns

We grouped the 14 game design patterns into four categories based on the gaming aspects they address; categories included (1) patterns related to body movements and/or the physical mechanics of the game, (2) patterns addressing issues about game rules, (3) patterns concerning perception issues, and (4) patterns concerning socialization issues. Each pattern was associated with one or more therapeutic goals denoting the aspects of BI therapy the pattern was intended to address. Table 3 summarized the patterns we identified and their main associated therapeutic goals.

Table 3. Summary of efficacy-centered game design patterns

Category	Pattern name	Main goals
Physical mechanics	Change Hands	Bilateral hand use
	Integrated Standing Duration	Standing
	Moving Different Body Parts	Insight into deficits
	Self-paced Weight Shifting	Dynamic balance; Weight shifting
	Weight Shifting to the Extremes	Weight shifting
Game rules	Fine Control	Weight shifting Balance
	Minimalist Task	Attention/ concentration
	Optimal/adjustable Pace	Processing Speed
	Randomized Events	Hand-eye coordination
	Step by Step	Sequencing; Command following
Perception	Focus and Distraction	Standing; Endurance
	Three-dimensional Space	Visual spatial abilities
Social	Collocated Multiplayer	Socialization
	Turn-based Multiplayer	Turn taking

4.2 Examples of Patterns

Each pattern in our pattern library contains (1) a name, (2) a category, (3) a set of associated therapeutic goals, (4) a problem statement describing conflicts in design, (5) a solution describing how the pattern can be used to resolve the problem, (6) examples of games that demonstrated this pattern, and (7) a list of related patterns (see section 4.3 for details). In this section, we provide one pattern example from each category.

4.2.1 Self-paced Weight Shifting

"Self-paced Weight Shifting" is a *physical mechanics* pattern addressing the *dynamic balance* and *weight shifting* goals.

Problem: Practicing dynamic balance often includes activities involving weight shifting (side-to-side and/or front-to-back). Games that require weight shifting at a fixed pace (e.g. Soccer heading on Wii Fit which requires players to weight shift to hit soccer balls kicked in at a fixed pace) were not rated as effective at addressing dynamic balance by therapists. Patients with dynamic balance issues often have limited reaction times that affect their reaction to fix-paced events.

Solution: Allow players to adjust the timing of weight shifting according to their own abilities. Do not impose fix-paced actions.

Example games:

- Wii Fit - *Table Tilt*: Player weight-shifts on a balance board in all directions to tilt a table and guide marbles through holes. There are no fix-paced events and players can perform weight shifting at their pace.
- Wii Fit - *Penguin Slide*: Player weight-shifts from side to side to control a penguin that slides on an iceberg to catch fish jumping out from the water. While the fish jump out in a fixed pace, players do not have to follow that pace to catch them.
- Kinect Sports - *Soccer Target Kick*: Player kicks soccer balls to hit the targets in a self-paced manner. Note that kicking involves weight shifting, especially when alternating legs.

Related patterns:

- Sometimes combined with *Weight Shifting to the Extremes* to further support practice of weight shifting.
- Can be combined with *Moving Different Body Parts* to support weight shifting in all directions.
- This pattern facilitates a sense of autonomy and thus can encourage player motivation. As such, it can be used to promote *Focus and Distraction*.
- *Optimal/adjustable Pace* mainly concerns the pace of events happening in the game, while this pattern concerns the pace of player actions.

4.2.2 Randomized Events

"Randomized Events" is a *game rules* pattern addressing the *hand-eye coordination* goal.

Problem: Practicing hand-eye coordination abilities usually involves perception and reaction to events. A game with periodical/predicable events can limit its effectiveness on rehabilitation of hand-eye coordination abilities.

Solution: Make events appear in a randomized manner to introduce uncertainty in the game. A fairly fast pace is often desired but the speed needs to match patient abilities. A human opponent with a matching skill or an adjustable AI opponent can usually provide unpredictable events in an optimized pace.

Example games:

- Wii Sports Resort - *Speed Slice*: Player swings the Wii remote in the direction specified on an object when it

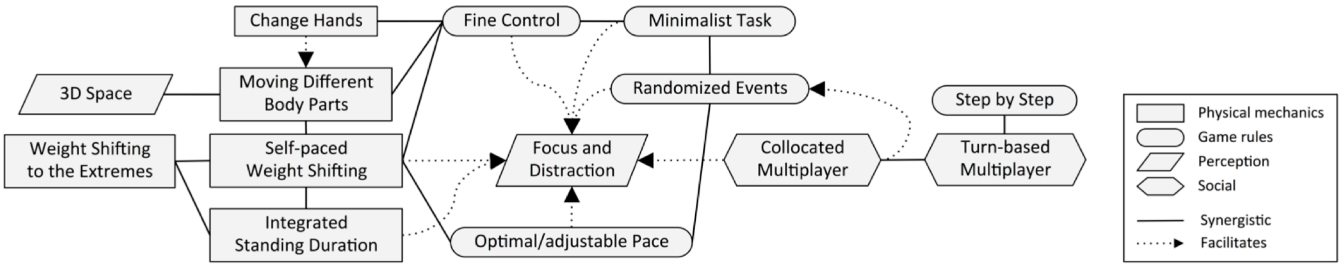

Figure 5. Relationships among efficacy-centered game design patterns

appears. The direction is randomized and the player needs to react on the specified direction within a time limit. However, the speed of this game is not adjustable; so it can only be used for high-level patients.

- Kinect Sports - *Table Tennis*: Player plays table tennis with an AI or another player. Player needs to react on the direction and speed of the ball and swing their arm accordingly. There are several levels of AI that player can choose to match their abilities.

Related Patterns:

- Usually used with *Optimal/adjustable Pace* to make sure the *Randomized Events* happens in a pace that matches player abilities.
- *Randomized Events* can promote *Focus and Distraction*.
- Supporting real-time (i.e. not turn-based) *Collocated Multiplayer* can be a way to create *Randomized Events*.

4.2.3 Focus and Distraction

"Focus and Distraction" is a *perception* pattern addressing the goals of *standing* and *endurance*.

Problem: Therapists may use games to promote patients' endurance (e.g. standing endurance). However, for patients who have had a BI standing and moving usually require a considerable amount of effort. A less engaging gaming experience will discourage the efforts to practice for an extended time.

Solution: Provide intriguing gaming elements and/or activities that promote concentration for players to be fully focused on the game and be "distracted" from the fact that they are standing/moving.

Example games:

- Wii Fit - *Table Tilt*: The game has a very clear goal and a straightforward task – to guide the marble to drop through the hole. The game features detailed control to support concentration and focus.
- Wii Fit - *Penguin Slide*: The theme and music of the game provides good distraction for suitable patients. Keeping the penguin on the iceberg is a straightforward task with appropriate challenge that promotes focus.

Related Patterns:

- Can be facilitated by many patterns such as *Integrated Standing Duration*, *Self-paced Weight Shifting*, *Fine Control*, *Minimalist Task*, *Optimal/adjustable Pace*, *Randomized Events*, and *Collocated Multiplayer*.

4.2.4 Collocated Multiplayer

"Collocated Multiplayer" is a *social* pattern addressing the *socialization* goal.

Problem: Patients who have had a BI need to be connected with their friends and family, their community, and the rest of the world. Some patients have difficulty socializing with other people due to their disabilities caused by BI.

Solution: Games can create a "safe" socialization space. Include collocated multiplayer features to encourage in-person social interaction. Preferably, include real-life activities players are already familiar with (e.g. golfing) to facilitate socialization.

Example games:

- Wii Sports or Kinect Sports - *Bowling*: Bowling alleys are usually social spaces in real life. A video game of bowling naturally supports collocated social interaction and attracts players who used to bowl prior to BI.

Related Patterns:

- Can be used to create *Randomized Events* and facilitate *Focus and Distraction*.
- Can be used with *Turn-based Multiplayer* to support in-person socialization and turn taking.

4.3 Relationships among Patterns

Design patterns can interact with each other in various ways. We identified two major types of relationships among patterns in our library (see Figure 5 for a summary of prominent relationships):

(1) Certain patterns can be used together to provide synergistic effects targeting on multiple therapeutic goals (i.e. synergistic relationship). For example, *Self-paced Weight Shifting* can be used with *Weight Shifting to the Extremes* and *Moving Different Body Parts* to address a combination of therapeutic goals such as weight shifting, dynamic balance, and insights into deficits.

(2) Using some patterns can promote or facilitate other patterns (i.e. facilitative relationship). For example, *Focus and Distraction* can be facilitated using patterns such as *Randomized Events* and *Collocated Multiplayer*.

4.4 Using the Patterns

Björk and Holopainen (2004) suggested that game design patterns can be used to support game designers in (1) brainstorming game design ideas, (2) expanding and refining conceptual design, (3) generating solutions to game design considerations, and (4) communicating and documenting game design [6]. While our patterns support those uses, we argue that the efficacy-centered patterns are best used to generate game design ideas when the designers need information about the intended therapeutic goals and the target players who have had a BI. In other words, our patterns help game designers understand needs in BI therapy by providing information about abstract activities that are effective in addressing certain BI therapy goals; some patterns also include information about considerations in BI therapy-centered game design (e.g. player abilities).

For example, if a game designer aims to design games that focus on improving balance and supporting weight-shifting exercises, he or she may consider instantiating patterns such as *Self-paced Weight Shifting* and *Fine Control* to generate the main game mechanics. If their goal is also to help the patients overcome neglect on one side of the body, they may also consider involving *Moving Different Body Parts*. By checking the related patterns of *Self-paced Weight Shifting*, they may become aware of the pattern *Optimal/adjustable Pace*, which they may use to accommodate a wider range of player abilities.

5. DISCUSSION

Our efficacy-centered game design patterns can serve as a common language for designing BI rehabilitation games and facilitate mutual understanding among game designers and therapists who focus on BI. Our pattern library is obviously not a comprehensive pattern language for BI therapy-centered game design (see section 5.1). However, we argue that our patterns cover the most common goals in BI therapy and included the most prominent game design elements that are effective at addressing these goals. Further, adopting the concept of design patterns allowed us to capture information about the most effective games for BI rehabilitation in a structure that can facilitate expansion of this body of design knowledge. While we plan to continue working towards building a more comprehensive pattern library for BI rehabilitation games, we also invite researchers and practitioners in this area to contribute to this effort.

In addition, design patterns helped us distill multiple variables from the large volumes of data we gathered about COTS game use in real-world therapy settings; in other words, patterns facilitated sense-making of our data for designers who are interested in creating games for BI rehabilitation. Further, our data-driven approach facilitated pattern extraction from successful COTS games. This approach strengthened the validity of our patterns and will be used in future work to expand our pattern library. We speculate that it can also be applied to related areas such as design patterns for accessible games in general.

It is worth noting that, as all kinds of design patterns, our efficacy-centered patterns should not be considered as guidelines that designers "should" follow. Instead, designers are advised to treat our patterns as a toolkit that help them generate creative game design ideas [6]. For this reason, we strived to describe our patterns in a higher level of abstraction. In addition, rehabilitation games are more than mere efficacy. They need to create an engaging experience to motivate patients engaged in the game [8]. As such, designers need to examine other game design considerations such as preference and abilities of their target players in order to create successful games for BI rehabilitation.

5.1 Limitations and Future Work

In this work, we only focused on the creation of efficacy-centered patterns. In future work, we plan to generate patterns that focus on other aspects of BI therapy games such as player experience and accessibility. Additionally, we will evaluate the effectiveness of these patterns with game designers and therapists. Further, the game therapy cases we have gathered so far were skewed towards physical goals and the most popular games; this limited the coverage of our pattern library. We are currently expanding our case gathering process to include a more diverse set of games; we are also trying to gather more cases focused on cognitive and social goals. In addition, we also plan to create an online library of therapy-centered game design patterns and create tools to help game designers who are interested in designing games for BI therapy to browse and choose appropriate patterns for their target players.

6. ACKNOWLEDGMENTS

Our thanks to the participating therapists from Schwab and Marianjoy Rehabilitation Hospitals. This work was funded by grants from DePaul's research council and a joint grant program with DePaul and Rosalind Franklin Universities.

7. REFERENCES

[1] About Brain Injury: *http://www.biausa.org/about-brain-injury.htm*. Accessed: 2015-03-24.

[2] Alankus, G., Lazar, A., May, M. and Kelleher, C. 2010. Towards customizable games for stroke rehabilitation. *Proceedings of the 28th international conference on Human factors in computing systems CHI '10* (New York, NY, USA, 2010), 2113–2122.

[3] Alexander, C., Ishikawa, S. and Silverstein, M. 1977. *A Pattern Language: Towns, Buildings, Construction*.

[4] Annema, J.-H., Verstraete, M., Vanden Abeele, V., Desmet, S. and Geerts, D. 2010. Videogames in therapy: a therapist's perspective. *Proceedings of the 3rd International Conference on Fun and Games - Fun and Games '10* (New York, NY, USA, 2010), 94–98.

[5] Betker, A.L., Desai, A., Nett, C., Kapadia, N. and Szturm, T. 2007. Game-based exercises for dynamic short-sitting balance rehabilitation of people with chronic spinal cord and traumatic brain injuries. *Physical therapy*. 87, 10 (2007), 1389–1398.

[6] Björk, S. and Holopainen, J. 2004. *Patterns in game design*. Charles River Media.

[7] Borchers, J.O. 2001. A pattern approach to interaction design. *AI & Society*. 15, (2001), 359–376.

[8] Buday, R., Baranowski, T. and Thompson, D. 2012. Fun and Games and Boredom. *Games for Health Journal*. 1, 4 (2012), 257–261.

[9] Burke, J.W., McNeill, M.D.J., Charles, D.K., Morrow, P.J., Crosbie, J.H. and McDonough, S.M. 2009. Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*. 25, 12 (2009), 1085–1099.

[10] Deutsch, J.E., Brettler, A., Smith, C., Welsh, J., John, R., Guarrera-Bowlby, P. and Kafri, M. 2012. Nintendo Wii Sports and Wii Fit Game Analysis, Validation, and Application to Stroke Rehabilitation. *Topics in Stroke Rehabilitation*. 18, 6 (2012), 701–719.

[11] Elaklouk, A.M. and Zin, N.A.M. 2012. Requirements for Game Based Cognitive Intervention System for Acquired Brain Injury. *GSTF Journal on Computing*. 2, 3 (2012), 25–31.

[12] Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F.I., Perry, J.C. and Keller, T. 2008. Improving patient motivation in game development for motor deficit rehabilitation. *Proceedings of the 2008 International Conference in Advances in Computer Entertainment Technology - ACE '08* (New York, New York, USA, 2008), 381–384.

[13] Gamma, E., Helm, R., Johnson, R.E. and Vlissides, J. 1995. *Design patterns: elements of reusable object-oriented software*.

[14] Garrido, J. and Marset, I. 2013. Balance disorder rehabilitation through movement interaction. *PervasiveHealth '13 Proceedings of the 7th International Conference on Pervasive Computing Technologies for Healthcare* (2013), 319–322.

[15] Gil-Gómez, J.-A., Lloréns, R., Alcañiz, M. and Colomer, C. 2011. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. *Journal of neuroengineering and rehabilitation*. 8, 30 (Jan. 2011), 1–9.

[16] Gillen, G. 2010. *Stroke Rehabilitation: A Function-Based Approach*. Mosby.

[17] Goude, D., Björk, S. and Rydmark, M. 2007. Game design in virtual reality systems for stroke rehabilitation. *Studies in Health Technology and Informatics*. 125, (2007), 146–148.

[18] Hardy, J. and Scanlon, M. 2009. The Science Behind Lumosity (Commercial web page). *Lumos Labs*.

[19] Hullett, K. and Whitehead, J. 2010. Design patterns in FPS levels. *Proceedings of the Fifth International Conference on the Foundations of Digital Games - FDG '10* (New York, New York, USA, 2010), 78–85.

[20] Huynh-Kim-Bang, B., Wisdom, J. and Labat, J.-M. 2010. Design Patterns in Serious Games: A Blue Print for Combining Fun and Learning. *Project SE-SG*.

[21] Jintronix: 2010. *http://www.jintronix.com*.

[22] Kam, M. and Rudraraju, V. 2007. Mobile gaming with children in rural India: Contextual factors in the use of game design patterns. *Situated Play, Proceedings of DiGRA 2007 Conference* (2007).

[23] Kelle, S., Klemke, R. and Specht, M. 2011. Design patterns for learning games. *International Journal of Technology Enhanced Learning*. 3, 6 (2011), 555–569.

[24] Lange, B., Chang, C.-Y., Suma, E., Newman, B., Rizzo, A.S. and Bolas, M. 2011. Development and evaluation of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (Jan. 2011), 1831–1834.

[25] Lange, B., Flynn, S. and Rizzo, A. 2009. Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. *Physical Therapy Reviews*. 14, 5 (Oct. 2009), 355–363.

[26] Lemay, P. 2007. Developing a pattern language for flow experiences in video games. *DiGRA '07 - Proceedings of the 2007 DiGRA International Conference: Situated Play* (2007), 449–455.

[27] Lewis, C., Wardrip-Fruin, N. and Whitehead, J. 2012. Motivational game design patterns of 'ville games. *Proceedings of the International Conference on the Foundations of Digital Games - FDG '12* (New York, New York, USA, 2012), 172–179.

[28] Marne, B., Wisdom, J., Huynh-kim-bang, B., Paris, J. and Labat, J. 2012. A Design Pattern Library for Mutual Understanding and Cooperation in Serious Game Design. *Intelligent Tutoring Systems*. Springer. 135–140.

[29] McClanachan, N.J., Gesch, J., Wuthapanich, N., Fleming, J. and Kuys, S.S. 2013. Feasibility of gaming console exercise and its effect on endurance, gait and balance in people with an acquired brain injury. *Brain injury*. 27, 12 (Jan. 2013), 1402–8.

[30] MIRA: 2012. *http://www.mirarehab.com*.

[31] Paavola, J.M., Oliver, K.E. and Ustinova, K.I. 2013. Use of X-box Kinect Gaming Console for Rehabilitation of an Individual with Traumatic Brain Injury: A Case Report. *Journal of Novel Physiotherapies*. 03, 01 (2013), 1–6.

[32] Projections of mortality and burden of disease, 2004-2030: 2004. *http://www.who.int/entity/healthinfo/global_burden_disease/projections2004/*. Accessed: 2015-03-17.

[33] Putnam, C. and Cheng, J. 2014. Therapist-centered requirements: A multi-method approach of requirement gathering to support rehabilitation gaming. *Proceedings of the IEEE 22nd International Requirements Engineering Conference (RE 2014)* (2014), 13–22.

[34] Putnam, C., Cheng, J. and Seymour, G. 2014. Therapist Perspectives: Wii Active Videogames Use in Inpatient Settings with People Who Have Had a Brain Injury. *Games for Health Journal*. 3, 6 (Dec. 2014), 366–370.

[35] Quick Facts About Brain Injury: *http://www.biausa.org/bia-media-center.htm*. Accessed: 2015-03-17.

[36] Rand, D., Kizony, R. and Weiss, P.L. 2004. Virtual reality rehabilitation for all : Vivid GX versus Sony PlayStation II EyeToy. *Proceedings of the 5th International Conference Series On Disability, Virtual Reality and Associated Technologies (ICDVRAT)* (2004), 87–94.

[37] Rose, F.D., Brooks, B.M. and Rizzo, A. a 2005. Virtual reality in brain damage rehabilitation: review. *Cyberpsychology & behavior : the impact of the Internet, multimedia and virtual reality on behavior and society*. 8, 3 (Jun. 2005), 241–62.

[38] Silver, J.M., McAllister, T.W. and Yudofsky, S.C. 2011. *Textbook of traumatic brain injury*. American Psychiatric Publishing, Inc.

[39] Smith, G., Anderson, R., Kopleck, B., Lindblad, Z., Scott, L., Wardell, A., Whitehead, J. and Mateas, M. 2011. Situating Quests: Design Patterns for Quest and Level Design in Role-Playing Games. *Proceedings of the 4th international conference on Interactive Digital Storytelling (ICIDS'11)* (2011), 326–329.

[40] Thompson, D., Baranowski, T., Buday, R., Baranowski, J., Thompson, V., Jago, R. and Griffith, M.J. 2010. Serious Video Games for Health: How Behavioral Science Guided the Development of a Serious Video Game. *Simulation & gaming*. 41, 4 (Aug. 2010), 587–606.

[41] Yavuzer, G., Senel, a., Atay, M.B. and Stam, H.J. 2008. "Playstation eyetoy games" improve upper extremity-related motor functioning in subacute stroke: A randomized controlled clinical trial. *European Journal of Physical and Rehabilitation Medicine*. 44, 3 (2008), 237–244.

[42] Zickefoose, S., Hux, K., Brown, J. and Wulf, K. 2013. Let the games begin: a preliminary study using attention process training-3 and Lumosity™ brain games to remediate attention deficits following traumatic brain injury. *Brain injury : [BI]*. 27, 6 (2013), 707–16.