GAMES FOR HEALTH JOURNAL: Research, Development, and Clinical Applications
Volume 4, Number 4, 2015

DOI: 10.1089/g4h.2014.0122

Original Articles

User-Centered Design of a Controller-Free Game for Hand Rehabilitation

Rachel Proffitt, OTD, OTR/L,[1] Marisa Sevick, OTD, OTR/L,[2]
Chien-Yen Chang, MS,[3] and Belinda Lange, PhD[3]

Abstract

Objective: The purpose of this study was to develop and test a hand therapy game using the Microsoft (Redmond, WA) Kinect® sensor with a customized videogame.

Materials and Methods: Using the Microsoft Kinect sensor as an input device, a customized game for hand rehabilitation was developed that required players to perform various gestures to accomplish a virtual cooking task. Over the course of two iterative sessions, 11 participants with different levels of wrist, hand, and finger injuries interacted with the game in a single session, and user perspectives and feedback were obtained via a questionnaire and semistructured interviews.

Results: Participants reported high levels of enjoyment, specifically related to the challenging nature of the game and the visuals. Participant feedback from the first iterative round of testing was incorporated to produce a second prototype for the second round of testing. Additionally, participants expressed the desire to have the game adapt and be customized to their unique hand therapy needs.

Conclusions: The game tested in this study has the potential to be a unique and cutting edge method for the delivery of hand rehabilitation for a diverse population.

Introduction

The etiology of hand and wrist injuries varies depending on the circumstances surrounding the injury. In the past several decades, there has been a shift in workforce injuries away from blue collar–related crush or tear injuries to secretarial and computer-related repetitive motion/overuse injuries such as carpal tunnel syndrome or De Quervain's syndrome.[1] Carpal tunnel syndrome is the costliest workplace injury, resulting in the most days off of work and the highest cost of health care for workplace-related injuries.[1] In athletics and recreational sports, injuries to the hand and wrist are common among sports that involve repetitive motion (e.g., tennis) and loading to the hand and wrist area (e.g., gymnastics), commonly resulting in crush injuries.[2] Nearly 50 percent of athletes will sustain an injury to the wrist and/or hand, and 25–50 percent of those are due to overuse. Hand impairments and injuries can also occur from nonworkplace and nonathletic situations such as a motor vehicle accident, a neurological disease or event (e.g., stroke), and the aging process (e.g., arthritis). For example, at least 50 percent of persons over the age of 65 years with stroke report hemiparesis, or paralysis of one side of the body, 6 months after the event.[3] Hemiparesis can involve the wrist and the hand in combination with the rest of the upper extremity.

Hand therapy for recovery of function after an injury is often a one-on-one process between the therapist and patient. In order to determine the most appropriate methods for a patient, a hand therapist will evaluate several factors, including current and past activities, patient goals, functional strength, sensation, range of motion, coordination, scar tissue characteristics, pain, and signs and symptoms of healing.[4] Using the evaluation findings, the therapist will work with the patient to determine his or her prognosis and initial plan of care. Treatment techniques vary and are frequently dependent on contraindications to certain movements or environmental conditions.

Therapists frequently use and prescribe exercises for patients to complete during therapy sessions and at home.[4] The motivating and engaging characteristics of virtual reality (VR) games can be used to provide stimulating environments in which patients can complete prescribed exercises. Several VR systems and robotic devices have been developed over the past two decades with promising results. Robotic systems provide accurate measures of patient performance through integrated sensors; however, most of these systems require

[1]Mrs. T.H. Chan Division of Occupational Science and Occupational Therapy and [3]Institute for Creative Technologies, University of Southern California, Los Angeles, California.
[2]Department of Occupational Therapy, Creighton University, Creighton, Nebraska.

the patient to don a glove or exoskeleton, are still only being used in a clinical or laboratory setting, and are heavy and encumbering and require the skill of an engineer or technician to set up.[5–8] Devices with associated gloves also eliminate patients with open wounds or other disfigurations of the hand.

The Microsoft (Redmond, WA) Kinect® sensor has been incorporated into a variety of customized VR rehabilitation systems.[9,10] Benefits of using the Kinect include elimination of the need to don wearable sensors or hold controllers to record performance (e.g., kinematic) data, portability across settings, and low cost (as of this writing, the Kinect can be purchased for $99). We have recently been exploring the capabilities of the Kinect sensor in tracking the movements of the hand with the potential for the device to be used as a controller-free tool for hand therapy. We developed a basic prototype that demonstrated the tracking functions of the Kinect sensor for the normal, uninjured human hand. The purpose of this proof-of-concept study was to explore the tracking capabilities of the Kinect sensor for a diverse hand rehabilitation patient population with a variety of injuries and refine a basic prototype of a hand rehabilitation game.

Materials and Methods

User-testing methodology

The user-centered design process was used for development of this VR-based hand therapy game. This study included two iterations of the user-centered design process. A basic prototype was developed, examined through comprehensive user testing, modified, and re-examined through user testing. This process has been used in the development of our other games for rehabilitation.[11,12]

Participants

The objective of this study was to explore the tracking capabilities of the Kinect with patients with a variety of injuries. Prior to this study, the tracking algorithm and prototype game had only been tested with participants without injuries; therefore minimal criteria were used for participant inclusion. Participants were included if they were (1) over the age of 18 years, (2) were currently receiving hand therapy as a covered rehabilitation service at a local hand therapy clinic, and (3) could understand English language as instructions were only available in English (at this time). This study was approved by the Institutional Review Board at the University of Southern California. Informed consent was obtained from all participants prior to taking part in the study.

In total, 11 adults participated in two separate occurrences of the user testing. Five interacted with the initial prototype (P1), and six interacted with the second, revised prototype (P2). The participants had a variety of injuries, including crush injury to the hand from work machinery (major involvement of three digits, minor involvement of the wrist), hemiplegia with hand involvement (minor), distal phalanx amputation, finger fractures (major involvement of two digits), wrist fracture from a fall (moderate involvement at the wrist with associated limitations in the forearm), sport-related wrist fracture (minor involvement of both wrist and hand), and nerve injury involving bilateral wrists (moderate) following a car accident. Participants ranged in age from 18 to 85 years, and all users except one had experience with some type of technology. Most participants had experience with a computer and cell phone; however, participants reported minimal videogame usage. Those who had used videogames were younger in age. Table 1 shows the demographic characteristics of the participants.

User-testing process

Participants completed user testing within a local hand therapy clinic. First, the participant completed a demographic and technology use questionnaire. Then participants interacted with the game for approximately 10–15 minutes. The total time of interaction with the game varied on the individual's ability to complete the in-game tasks. Each participant played through the game once to determine the ability of the Kinect to track the participant's hand and determine usability of the prototype game. Following gameplay, a semistructured interview was completed with each participant to obtain feedback on gameplay. Participants also completed a posttesting questionnaire that was derived from Microsoft and IBM usability surveys[13,14] about their overall experience. The user-testing process including gameplay, and the semistructured interview was recorded using Morae software.[15] Using Morae, video of gameplay, including the movements, facial expressions, and verbalizations, was recorded and synchronized with a recording of on-screen gameplay.

Description of the game

The ''Cooking'' game prototypes were developed using the game engine Unity.[16] The game was run on a laptop connected to a Kinect camera placed on the table in front of the laptop. The application used the Kinect for Windows Framework to communicate with the Kinect sensor and to translate user movements and gestures into game actions.

Table 1. Demographic Characteristics of the Study Population

Variable	n
Age (years)	
18–30	5
30–40	2
50–60	2
70–90	2
Gender	
Male	8
Female	3
Computer usage	
Yes	9
No	2
Videogame systems	
None	8
One	1
Two or more	2
Frequency of gameplay	
None	8
Few times/week	1
Few times/month	1
Few times/year	1

Users were seated at least 4 feet and no more than 7 feet from the Kinect camera.

The game involved the task of cooking a steak, including multiple steps. A lateral pinching motion was required to begin the game. After the game began, different hand gestures were required to complete actions of the cooking task with the result of preparing a steak. The hand gestures were selected from common exercises and movements prescribed by hand therapists and using the clinical expertise of two research team members. The gestures/exercises in the game do not target a specific deficit or injury; rather, the gestures are used in everyday life to achieve functional tasks and goals. The gestures and associated in-game actions used in both prototypes are as follows:

- Lateral ‘‘key’’ pinch: start game, turn on/off stove (select knob)
- Wrist rotation (supination/pronation): turn on/off stove (turn knob)
- Gesture numbers 1–4: select a steak seasoning
- Tip to tip index finger pinch: season steak
- Whole hand flexion/extension: pick up pan, pick up steak
- Translation of arm in space: move pan to stove, move steak to plate, chop lemon

The parameters for successful completion of each gesture were predefined in the gesture recognition algorithm based on normal hand movements. The game is also based solely on successful completion of the gestures. Game elements such as time limits, levels, and a scoring system were not incorporated into these prototypes.

Data analysis

Data analysis was completed after each round of user testing. The interviews and recordings of gameplay were analyzed using the Morae software. Two independent researchers coded the data using the process of open coding.[17] The questionnaire data were analyzed separately, and the ratings on specific questions were used to support the qualitative data. Themes emerged from the codes, and three distinct categories of themes became apparent: Positive Elements, Limitations in Gameplay, and Suggestions for Future Use.

Results

Prototype development process

The development of the game through the prototype phases followed the iterative user-centered design process. P1 was completed prior to initial user testing. After the first round of data was analyzed, changes were made to P1 to produce P2, which was used in the second round of user testing. Data were analyzed from the second round of user testing, and a third prototype is currently being developed from the feedback and themes that emerged. The two prototypes (P1 and P2) are described below along with additional results of the user testing.

User-testing themes

Positive elements. The participants demonstrated enjoyment in playing the game. Many participants expressed this enjoyment through facial expressions throughout gameplay and verbally expressed enjoyment at the conclusion of the game. An overall valued aspect of the game was the interactive nature of the game. As one participant commented: ‘‘It [the game] is interesting, I like how it is interactive, it was nice.’’ Another compared it with traditional therapy methods, stating ‘‘[Aspect liked] probably that you got to interact with it and do stuff rather than just doing stretching.’’ Others commented on specific aspects of the game. As one participant stated, ‘‘I liked that it was responsive, like when you pressed enter and it beeped.’’

Many of the visual aspects of the game were very basic and easy for the participants to see. However, some participants expressed difficulty deciphering overlapping items, including the on-screen words. One participant expressed this frustration: ‘‘It was kind of hard to read but it was pretty cool.’’ To improve gaming visuals in P2, words were moved, and color was changed to enhance contrast and allow increased readability for the users (Table 2).

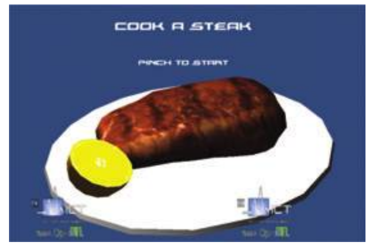
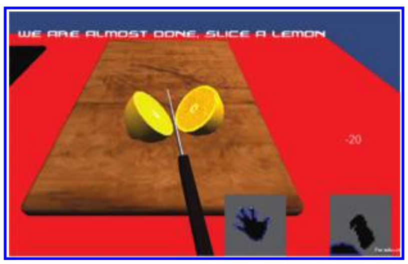
During the trial of P1, participants depended on verbal cues and demonstrations from the researchers in order to learn the corresponding gestures for each in-game action (Table 2). Following the inclusion of on-screen instructions (text and images), participants were able to complete the game with fewer verbal cues and demonstrations from the researchers (Table 2). Participants still required increased time to read and understand the on-screen directions. However, once participants learned the gestures, they were able to transition throughout the game more efficiently. Participants responded positively to the on-screen directions; as one participant stated, ‘‘They were good [the pictures]. It was nice to have them in case I couldn’t read what I was supposed to do I could look and see what I was supposed to do.’’

Limitations in gameplay. Throughout user testing, it became apparent that the tracking capabilities of the Kinect sensor varied depending on the size of the hand and fingers of the participant. Specifically, recognition of the hand and individual digits was poor with male participants during both user-testing sessions. The Kinect sensor and associated algorithm were completely unable to recognize the hands of two participants despite multiple attempts at rearranging angles, distances, and assuming different hand postures. Additionally, one participant with a finger amputation (digit 3, distal interphalangeal joint) was unable to be tracked by the Kinect sensor.

Suggestions for future use. The users desired additional gestures beyond the currently incorporated gestures that focused on the specific deficits/limitations that they were experiencing as a result of their hand injury. One user stated, ‘‘I would have really liked to see a lot more flexion, and this kind of movement because this is really what I need to be working on,’’ and another stated: ‘‘[I would like] more pinching exercises with different fingers.’’ In P2, the ability to choose a right- or left-hand–based gameplay at the beginning was added (Table 2).

After trialing the game, participants felt that they were likely to play the game in the future. They also felt that the utilization of such a game during therapy or in the home setting would be beneficial. One participant stated, ‘‘My big thing also is a lot of times you probably have a lot of

Table 2. Descriptions of the Two Game Prototypes

Initial prototype game (P1)	*Second prototype game (P2)*
1. Gestures for subtasks of the cooking activities predetermined (gestures mainly involved right hand, making it not as therapeutic for those with left hand involvement)	1. Gestures for subtasks of the cooking task were predetermined but based on which hand was used for pinch gesture to start game (if right utilized, gestures were mainly right dominant)
	
2. Basic on-screen directions that described the in-game task (i.e.,''flip the steak'') with no on-screen directions on how to execute steps with hand gestures	2. On-screen directions for executing steps (including pictorial depictions of actions)
	
3. All wording within game was in white, often difficult for users to read	3. All wording within game was in yellow, contrasting background better
	

Color graphics available online at www.liebertonline.com/g4h

repetitive exercises that you have to do [during therapy], and you know how boring those get. So if you can do those in a fun game where you don't realize you have done 100 flexion of that digit, but you then cook a steak.'' One participant had high enthusiasm regarding using the game as a rehabilitation tool and stated, ''Sure, take it home, plug the stick into the computer and they can stand there and play with that. It would be good.''

Discussion

The purpose of this study was to explore the tracking capabilities of the Microsoft Kinect sensor for a diverse hand rehabilitation patient population with a variety of injuries and to refine a basic prototype of a hand rehabilitation game. The main findings within the initial user testing were that the interactivity aspect of the game had the potential to lead to increased enjoyment by the users, the game can be used to engage a diverse population and clinical settings, and in order for the game to meet the needs of the diverse population, increased adaptability of the game would need to be built in. Each is discussed below.

An interactive game has the potential to lead to increased enjoyment

A frequent criticism that hand therapy patients have is the requirement of completing tedious, multiple repetitions of a movement. Findings from multiple research studies support the notion of mass repetitions for ideal motor recovery; unfortunately, many individuals do not follow through with these home exercise programs.[18] If exercises are enjoyable and are able to keep the attention of the patient, there is a higher likelihood that the patient will complete more repetitions. The interactive nature, and specifically the on-screen feedback received at the completion of gestures, was the most enjoyable feature of the prototype game. Therefore all these aspects were kept throughout the user-testing process in order to maintain the interactive nature of the games.

The game can be engaging for a diverse population

Injuries involving the wrist, hands, and fingers affect people of all ages, gender, and ethnicities. Many off-the-shelf videogames and VR games are often targeted toward younger male populations. Through user testing we were able to determine that all participants demonstrated enjoyment playing the game regardless of age, gender, or experience with game-specific technologies. The nature of injuries and the disorders were also varied. Despite the range of individual patient factors and rehabilitation needs, the prototype seems to appeal to users across the hand rehabilitation spectrum.

Potential of meeting the needs of diverse populations and clinical settings through adaptability

The user testing of the first two prototypes demonstrated positive results. The testing also identified the essential need for increased adaptability within the game. For this game to truly meet the needs of a diverse population of hand injuries, the game must allow for adaptability to each individual user's needs. Adaptations should include the ability to specify the gestures to be used in gameplay that will match the therapy goals and needs of the user. Adaptations should also include the ability to calibrate the system to the parameters of an individual's hand. The recognition difficulties of male hands is a current limitation of the prototype game, and future iterations of the prototype will address this issue through calibration. Calibration of each individual user truly allows for one game to be comprehensive enough to appeal to a diverse population but also be customizable to meet the individualized needs of that diverse population. A current prototype of the game has integrated custom calibrations and is being tested with participants of both genders.

Limitations

This study has some limitations. First, the preset gestures within the game were trialed with a fairly heterogeneous population of users. Therefore, the game did not always provide therapeutic value for every user. Second, the game also only had two iterations of the prototype. Future user-testing and feasibility studies need to be conducted to determine the applicability across users and settings. The inclusion of an adapted/customized setting in the game will increase the applicability for users. Third, this study was conducted at one hand rehabilitation site. Although the study participants ranged in age, gender, and nature of injury, it is difficult to generalize the findings to patients at other hand rehabilitation sites.

The prototypes explored in the study also lacked some clinical utility. Hand therapists (and occupational/physical therapists in general) are being increasingly pressured by insurance payors to provide objective data that document patient progress and show the necessity of rehabilitation services. The tracking algorithm for the game is based on gesture recognition and is not tracking/recording kinematics of the hand (e.g., range of motion of the index finger metacarpal phalangeal joint during pinching), nor is it recording the position of the hand in space relative to the Kinect sensor. Our other rehabilitation applications using the Kinect sensor have incorporated limb in space tracking and recording. Future version of the game will combine the two algorithms. We also plan to take advantage of the tracking capabilities of the recently released Microsoft Kinect 2.

Conclusions

The utilization of user testing allows for modifications and enhancements to the game to fit the needs of the end-users. With the objective for the game to be able to be used with a diverse population, testing within this population facilitated an understanding of required aspects to make the game meet this goal.

Acknowledgments

This study was supported by the Telemedicine and Advanced Technology Research Center at the U.S. Army Medical Research and Materiel Command (grant W911NF-04-D-0005) (Principal Investigator: B. Lange), the National Institute on Disability and Rehabilitation Research grant ''Optimizing Participation Through Technology: Rehabilitation Engineering Research Center'' (OPTT:RERC) (Principal Investigator: C.J. Winstein) (grant H133E080024), and a National Institutes of Health T32 Institutional Postdoctoral Training Grant ''TREET: Training in Rehabilitation Efficacy and Effectiveness Trials'' (grant 5T32HD064578-02) (Principal Investigator: F. Clark).

Author Disclosure Statement

No competing financial interests exist.

References

1. Bureau of Labor Statistics. Lost-Worktime Injuries and Illness: Characteristics and Resulting Days Away from Work. 2002. www.bls.gov/news.release/archives/osh2_03252004.pdf (accessed August 29, 2014).
2. Rettig AC. Athletic injuries of the wrist and hand part II: Overuse injuries of the wrist and traumatic injuries to the hand. Am J Sports Med 2004; 32:262–273.
3. Go AS, Mozaffarian D, Roger VL, et al. Heart disease and stroke statistics—2014 update: A report from the American Heart Association. Circulation 2014; 129:e28.
4. American Society of Hand Therapists. Position Paper on Hand Therapists' Scope of Practice. 2011. www.asht.org/sites/default/files/documents/2014/hand_therapists_scope_of_practice_paper_rev_100314.pdf (accessed August 29, 2014).
5. Fischer H, Stubblefield K, Kline T, et al. Hand rehabilitation following stroke: A pilot study of assisted finger extension training in a virtual environment. Top Stroke Rehabil 2007; 14:1–12.
6. Luo X, Kline T, Fischer HC, et al. Integration of augmented reality and assistive devices for post-stroke hand opening rehabilitation. Paper presented at the 27th Annual Conference on Engineering in Medicine and Biology, Shanghai, China, September 1–4, 2005.
7. Takahashi CD, Der-Yeghiaian L, Le V, et al. Robot-based hand motor therapy after stroke. Brain 2008; 131:425–437.

8. Kowalczewski J, Chong SL, Galea M, Prochazka A. In-home tele-rehabilitation improves tetraplegic hand function. Neurorehabil Neural Repair 2011; 25:412–422.
9. Lange B, Koenig S, Chang CY, et al. Designing informed game-based rehabilitation tasks leveraging advances in virtual reality. Disabil Rehabil 2012; 34:1863–1870.
10. Webster D, Celik O. Systematic review of Kinect applications in elderly care and stroke rehabilitation. J Neuroeng Rehabil 2014; 11:108–132.
11. Proffitt R, Lange B. User centered design and development of a game for exercise in older adults. Int J Tech Knowledge Soc 2013; 8:95–112.
12. Proffitt R, Lange B, Chen C, Winstein C. A comparison of older adults' subjective experience with virtual and real environments during dynamic balance activities. J Aging Phys Act 2015; 23:24–33.
13. Bangor A, Kortum P, Miller J. Determining what individual SUS scores mean: Adding an adjective rating scale. J Usability Stud 2009; 4:114–123.
14. Lewis JR. IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. Int J Human Comput Interact 1995; 7:57–78.
15. TechSmith. Morae [computer software]. Okemos, MI: TechSmith; 2015.
16. Unity Technologies. Unity 3D [computer software]. San Francisco, CA: Unity Technologies; 2015.
17. Corbin J, Strauss A, eds. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, 3rd ed. Thousand Oaks, CA: Sage; 2008.
18. Jurkiewicz MT, Marzolini S, Oh P. Adherence to a home-based exercise program for individuals after stroke. Top Stroke Rehabil 2011; 18:277–284.

Address correspondence to:
Rachel Proffitt, OTD, OTR/L
Mrs. T.H. Chan Division of Occupational Science & Occupational Therapy
University of Southern California
1540 Alcazar Street, CHP 133
Los Angeles, CA 90089

E-mail: Rachel.proffitt@usc.edu