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*Corresponding author: Jill Whitall, Department of Physical Therapy and Rehabilitation Science, School of Medicine, University of Maryland, 100 Penn street, Allied Health Building, Baltimore, MD 21201, USA; Faculty of Health Sciences, University of Southampton, Southampton, UK
E-mail: jwhitall@som.umaryland.edu

Reviewing editor:
Udo Schumacher, University Medical Center Hamburg-Eppendorf, Germany

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PHYSIOLOGY & REHABILITATION | RESEARCH ARTICLE

Kinect-based individualized upper extremity rehabilitation is effective and feasible for individuals with stroke using a transition from clinic to home protocol

Wan-wen Liao¹, Sandy McCombe Waller¹ and Jill Whitall^{1,2*}

Abstract: *Purpose:* To investigate the effectiveness and feasibility of Kinect-based upper extremity rehabilitation on functional performance in chronic stroke survivors. *Methods:* This was a single cohort pre-post test study. Participants ($N = 10$; mean age = 62.5 ± 9.06) engaged in Kinect-based training three times a week for four to five weeks in a university laboratory. To simulate a clinic to home transfer condition, individualized guidance was given to participants at the initial three sessions followed by independent usage. Outcomes included Fugl-Meyer assessment of upper extremity, Wolf Motor Function Test, Stroke Impact Scale, Confidence of Arm and Hand Movement and Active Range of Motion. Participant experience was assessed using a structured questionnaire and a semi-structured interview. *Results.* Improvement was found in Fugl-Meyer assessment scores ($p = 0.001$), Wolf Motor Function Test, ($p = 0.008$), Active Range of Motion ($p < 0.05$) and Stroke Impact Scale-Hand function ($p = 0.016$). Clinically important differences were found in Fugl-Meyer assessment scores ($\Delta = 5.70 \pm 3.47$) and Wolf Motor Function Test (Δ Time = -4.45 ± 6.02 ; Δ Functional Ability Scores = 0.29 ± 0.31). All participants could

ABOUT THE AUTHORS

Wan-wen Liao, OT, MS is a PhD candidate in the Department of Physical Therapy and Rehabilitation Science at University of Maryland Baltimore. Her research interest is in understanding the neural mechanisms of functional recovery after stroke and develops novel interventions to assist in stroke recovery.

Sandy McCombe Waller, PT, PhD, NCS is an associate professor in the same department and a Neurologic Clinical Specialist. Her research interests are in understanding mechanisms of neuroplasticity following stroke and the development of more effective post stroke rehabilitation interventions for the upper extremities and balance control.

Jill Whitall PhD, FNAK is a professor in the same department and a part-time professor in the Faculty of Health Sciences at the University of Southampton, UK. Her research focus is on understanding the development and principles of (re-) learning motor coordination and includes designing and testing novel interventions to aid stroke recovery.

PUBLIC INTEREST STATEMENTS

A low-cost 2D virtual reality-based system such as Microsoft Kinect has become an increasingly popular tool for continued stroke rehabilitation. Despite its popularity, the therapeutic methods and participants' perspectives towards use of this type of training remain largely unaddressed. In this study, we examined the effectiveness and feasibility of 4-weeks of Kinect-based upper extremity (UE) training for increasing functional performance in individuals with chronic hemiparesis. The protocols of Kinect-based training were individualized to each stroke participant by a physiotherapist and a protocol employed that can facilitate transition from the clinic to home environment. Results showed that Kinect-based UE rehabilitation can improve arm function and enhance the paretic arm engagement in daily activities. Participants could use the Kinect-based program independently after initial instruction. The individualization by therapists in the first few sessions appeared to facilitate transition from the clinic to home use.

use the system independently and recognized the importance of exercise individualization by the therapist. *Conclusions.* The Kinect-based UE rehabilitation provided clinically important functional improvements to our study participants.

Subjects: Rehabilitation Medicine; Assistive Technology; Physiotherapy

Keywords: virtual reality; arm; hemiparesis; exercise; gaming system; assistive technology

1. Introduction

Stroke is the leading cause of long-term adult disability in the United States (Mozaffarian et al., 2016). More than a half of survivors continue suffering from upper-limb hemiparesis post-stroke with only 5% of people recovering their full arm function (Gowland, deBruin, Basmajian, Plews, & Burcea, 1992). The persistent upper-limb dysfunction significantly impairs motor performance, and results in a serious decline in functional ability as well as quality of life (Mayo, Wood-Dauphinee, Côté, Durcan, & Carlton, 2002). Intensive and repeated practice with the paretic arm appears necessary to enhance arm recovery and facilitate neural reorganization (Kwakkel et al., 2004; Lohse, Lang, & Boyd, 2014; Nudo, Milliken, Jenkins, & Merzenich, 1996; Van Peppen et al., 2004). Nevertheless, the health-care system provides limited amounts and duration of therapy, making it difficult for stroke survivors to achieve maximal arm recovery before discharge from outpatient rehabilitation or home care (Hayward & Brauer, 2015; Lang et al., 2009). Therefore, identifying novel modalities that are accessible and affordable to the general public while allowing continued practice of the arm is imperative for improving long-term upper-limb outcomes after stroke.

One potential approach is the use of low-cost virtual reality (VR)-based systems, for example, the Microsoft Kinect system. The Kinect is a vision-based motion capturing system that can detect gesture and movements of the body through its RGA camera and depth sensors. It allows users to interact with the VR-based system without holding or wearing specialized equipment or markers for tracking. Users can play games or practice exercises using natural movements while observing the performance of their virtual avatars shown in real-time on the computer screen. Through this interactive observation and feedback, stroke survivors can correct their movements towards more normal patterns. Furthermore, the Kinect is small and portable, thus enabling stroke survivors to practice exercises in a familiar and private environment.

Despite its advantages, few studies have evaluated the use of Kinect for upper-limb rehabilitation in stroke survivors, and results have been varied partly due to differences in subject selection and the training programs adopted (Mousavi Hondori & Khademi, 2014; Webster & Celik, 2014). For example, some researchers adopted commercially available videogames such as Kinect Adventures as a form of arm training in addition to standard therapies (Lee, 2013; Sin & Lee, 2013). While positive effects were shown on muscle strength and arm impairments, these videogames were designed for entertaining purposes for a healthy population that did not address compensatory strategies such as abnormal arm and trunk movements that stroke survivors may perform during training. In addition, commercial videogames often involve complex movements that may be too difficult or too fast moving for individuals with hemiparesis, thus limiting the applicability of this type of Kinect-based training (Taylor, McCormick, Shawis, Impson, & Griffin, 2011). Other researchers have designed computer games specifically targeting individuals with stroke. Their results were generally promising; however, these impairment-oriented games were only tested in a single individual or a relatively small number of people in a few training sessions (Brokaw, Eckel, & Brewer, 2015; Chang, Chen, & Huang, 2011; Pastor, Hayes, & Bamberg, 2012). It is still unclear whether stroke survivors with different levels of arm ability could benefit from Kinect-based training. There is also a lack of quantitative, as well as, qualitative analysis regarding subjective perception of this specific kind of VR-based training in persons with stroke. Regardless of which gaming/exercising systems were used, the majority of Kinect rehabilitation studies were conducted in hospitals or laboratories where trainers supervised and assisted the training (Chang et al., 2011; Lee, 2013; Mousavi Hondori & Khademi, 2014; Pastor et al., 2012; Sin & Lee, 2013; Taylor et al., 2011; Webster & Celik, 2014). The applicability of

Kinect-based training as well as the therapeutic methods transferring from the clinical to home setting remain largely unaddressed.

The purpose of this study was to investigate the effectiveness and feasibility of a Kinect-based upper extremity (UE) training for increasing functional performance in individuals with chronic hemiparesis. In contrast to previous studies, we included participants spanning a large range of arm ability and employed training conditions that would determine the potential use of this system in the home environment. We further assessed stroke participants' experience and feedback regarding the Kinect-based UE training. We hypothesized that study participants would demonstrate improvements in paretic arm performance after Kinect-based UE training based on the fact that they would be undergoing repetitive task-related movements with feedback.

2. Methods

2.1. Participants

A purposeful sampling of participants with a range of arm ability were recruited from the local community. The inclusion criteria were: (1) age between 30 to 85 years, (2) unilateral post-stroke of at least 6 months (ischemic) or 12 months (hemorrhagic) stroke, (3) residual hemiparetic motor dysfunction of the arm, and (4) the ability to stand for 5 min continuously. Individuals were excluded if they had (1) a history of brain surgery, (2) self-report of acute functional impairment related to cardiovascular, pulmonary, metabolic, other neurologic, or musculoskeletal disease, (3) vision, or hearing problems that limit communication, and (4) inability to follow two step commands. Participants were initially contacted through a phone conversation. Each participant had participated in previous studies and had indicated willingness to be contacted to participate in future studies. On their first visit, after consenting, they were screened according to the above criteria. Participants were also observed to ensure that they did not have vision or hearing problems or functional impairments related to other diseases. Participants provided written informed consent, and all study procedures were approved by the University of Maryland Baltimore Institutional Review Boards.

2.2. Study design and procedures

This study was a single cohort pretest-posttest research design. Participants were assessed by an occupational therapist, who was not blinded to the purpose of the study, before and after Kinect-based upper extremity training. All outcome measures were performed following the guidelines in the literatures (Chen, Lewthwaite, Schweighofer, & Winstein, 2013; Duncan et al., 1999; van Exel et al., 2004; Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975; Norkin & White, 2009; Vellone et al., 2015; Whittall, Savin, Harris-Love, & Waller, 2006; Wolf et al., 2006). Participants performed training in a laboratory at the University of Maryland Baltimore for three times a week with a target of 4–5 weeks.

2.3. Intervention protocol

Microsoft Kinect for windows and a Kinect-based rehabilitation software program developed by Kangaroo Health Inc. were used for upper extremity training. The Kinect camera was synced with an all-in-one computer running Windows 8™ system positioned at a distance of approximately 2.5 m away from the participants to ensure the best line of sight. The software program included upper extremity exercises with a focus on shoulder and elbow movements. Training sessions began with a calibration by the Kinect system during which participants raised their arms in standing. The system then constructed virtual avatars for each participant (self-avatar). A virtual trainer was customized in the program to “lead” the exercise. Participants performed the exercises with both the virtual trainer to lead the exercises and their self-avatar visible to display real-time feedback of their movements. The program provided verbal feedback to participants to minimize common compensatory movements. For example, if they were rotating the trunk, the program would say “keep your body straight” and if they were abducting the shoulder, the program would say “keep your elbow close to your body”. There was also background music built into the system which played continuously

during training. The background music provided a comfortable and relaxed environment without interrupting the exercise. The volume was adjusted to the participant's preference.

The exercises performed in this study were: (1) elbow flexion-and extension, (2) shoulder flexion-and extension, (3) shoulder horizontal flexion-and extension, and (4) shoulder diagonal abduction-and adduction thus involving both single and multi-joint complex movements. These exercises were selected because they are critical elements of many daily activities. For example, elbow extension and shoulder flexion are both required when reaching to objects. More specifically, the shoulder horizontal/diagonal movements are important when reaching to objects at different orientations and height levels such as from a shelf. Participants performed these exercises bilaterally with both arms moving simultaneously in the same direction and unilaterally with the non-paretic and the paretic arm in standing or sitting based on their preference.

To simulate a condition where clinicians would instruct their patients in the clinic prior to discharge with home follow-up, a therapist individualized the Kinect-based training on parameters including the order and duration of the exercises and provided verbal guidance, where needed, on how to move the arms in the correct posture for the first three sessions. The trainers were also present to instruct participants on how to operate the program in the first three sessions. This input was then withdrawn for the remaining of the training sessions to simulate independent home use. Participants were expected to start the program, complete the calibration, perform the exercises according to program feedback, and change exercise sessions on their own. During these later sessions, the trainer left the room, came back briefly at half-way through and at the end. After each session, participants were asked whether they would like to alter anything about the session such as the amount of time for an exercise or the order. The trainer then adjusted the exercise program according to the participants' request. The duration of each session ranged from 45–60 min depending on each participant's ability to complete the exercises. All sessions were videotaped to monitor the progress of training.

2.4. Outcome measures

The primary outcomes included Fugl-Meyer assessment scale of the Upper Extremity (FMA), Wolf Motor Function Test (WMFT) and upper extremity active range of motions (AROM) for the shoulder and elbow. FMA was used to evaluate impairments of movements, coordination and reflexes of the shoulder, wrist and hand (Fugl-Meyer et al., 1975). The WMFT was used to assess upper-extremity motor function through timed (WMFT-TIME) functional-based tasks (WMFT-FAS) (Whitall et al., 2006). AROM of flexion, extension, abduction, horizontal abduction of the shoulder, and flexion and extension of the elbow were assessed following standardized procedures in the seated position (Norkin & White, 2009).

Secondary outcomes included the hand function portion of Stroke Impact Scale (SIS-HAND) and the Confidence in Arm and Hand Movement (CAHM). The SIS-HAND was used to evaluate self-perceived hand function of the paretic arm during daily tasks (Duncan et al., 1999; Vellone et al., 2015). The CAHM examined self-efficacy of arm and hand movements in daily activities performed in home and community contexts using either the affected arm/hand or both arms/hands (Chen et al., 2013; Wolf et al., 2006). Participants were asked how confident they were at the time of training to perform these tasks. A self-rated burden scale was used to assess the perception of burden at post-training (van Exel et al., 2004).

A structured questionnaire "Feedback Efficacy and System Evaluation (FEASE)" was developed for assessing the usability of Kinect-based training. It has three domains that evaluated the efficacy of visual feedback, avatars and arm exercises. Participants' experience and feedback about the Kinect system and UE training were also assessed during a semi-structured interview. The questions in the semi-structured interview included topics of acceptability and experience of the Kinect system and training, notable perceived changes in functional arm use, and suggestions for future improvements

of the training system. The FEASE questionnaire and semi-structured interview were given only at the post-training.

2.5. Statistical Analysis

The paired t-test was used to compare the value of pre-to post-intervention for all quantitative variables. A two-sided *p*-value of <0.05 was considered statistically significant. The effect size of each variable was also quantified using Cohen’s *d* formula which divided the differences of the mean scores between pre-and post-training by the standard deviation of the differences between pre-and post-training scores (Cohen, 1992). Qualitative data obtained from the semi-structured interview were analyzed based on qualitative content analysis in the following steps (Hsieh & Shannon, 2005; Sandelowski, 2000; Zhang & Wildemuth, 2009). First, all comments were transformed into written text and reviewed by two investigators independently to identify major themes that best described participants’ perception and feedback for the Kinect-based UE training. The emerged major themes were then assigned with singular codes. All comments were coded into each theme by three investigators independently. Any disagreements between investigators regarding coding of a particular comment were discussed until a consensus was reached.

3. Results

Table 1 shows the characteristics of the 10 participants. The averaged time post stroke was 11.3 ± 7.09 years and the averaged baseline FMA-UE scores were 37.40 ± 17.83 (range from 6–63). Participants completed 12–15 sessions of training based on their availability. All participants could operate the system step-by-step and run the program independently after the first three sessions of instruction from the trainer and the therapist.

3.1. Primary and secondary outcomes

Table 2 shows the baseline and mean absolute changes of scores at post-training for the paretic arm. For the primary outcomes, there were significant improvements in the FMA-UE scores (*p* = 0.001), WMFT-TIME (*p* = 0.008) and WMFT-FAS scores (*p* = 0.016). The FMA-UE changes ranged from 1–12 points; The WMFT-TIME changes ranged from 0 to –12.79 s and the WMFT-FAS score changes ranged from 0–0.93. The AROM of shoulder flexion (*p* = 0.006), abduction (*p* = 0.016), and horizontal adduction-abduction (*p* = 0.005), and elbow flexion (*p* = 0.038) and extension (*p* = 0.004) also significantly increased after training. In particular, the AROM of shoulder abduction and horizontal adduction-abduction showed the greatest improvements. For the secondary outcomes, there was a significant improvement of perceived hand function in the home and community environment based on the SIS (*p* = 0.047). No significant changes were found in the CAHM though participants did have an average positive increment of 6.87% post-training. For the self-rated burden scale, seven

Table 1. Demographics and clinical characteristics of the participants

| Participant ID | Age, years | Gender Male(M)/ Female(F) | Time since Stroke, years | Type of stroke | Affected side Right(R)/ Left(L) | Baseline FMA-UE scores |
|----------------|------------|---------------------------|--------------------------|----------------|---------------------------------|------------------------|
| 1 | 75 | M | 13 | Ischemic | R | 38 |
| 2 | 62 | M | 4 | Ischemic | R | 38 |
| 3 | 73 | F | 29 | Hemorrhage | L | 38 |
| 4 | 61 | F | 9 | Ischemic | L | 28 |
| 5 | 76 | M | 15 | Ischemic | L | 37 |
| 6 | 58 | F | 7 | Hemorrhage | L | 61 |
| 7 | 59 | F | 9 | Ischemic | L | 7 |
| 8 | 50 | M | 7 | Ischemic | L | 49 |
| 9 | 55 | M | 13 | Ischemic | L | 63 |
| 10 | 56 | F | 7 | Ischemic | R | 15 |

Note: FMA-UE, Fugl-Meyer Assessment Scale of Upper Extremity.

Table 2. Changes of outcomes from pre- to post-training

| Outcomes | Baseline, (Mean ± SD) | Absolute Changes, (Mean ± SD) | p-value | Effect size <i>d</i> |
|---|-----------------------|-------------------------------|--------------------|----------------------|
| | N = 10 | N=10 | | |
| FMA-UE total (scores) | 37.40 ± 17.83 | 5.70 ± 3.47* | 0.001 [†] | 1.64 |
| WMFT-TIME (seconds) | 41.54 ± 41.77 | -4.45 ± 6.02* | 0.008 [†] | 1.07 |
| WMFT-FAS (scores) | 2.57 ± 1.04 | 0.29 ± 0.31* | 0.016 [†] | 0.94 |
| Shoulder Flexion (Degrees) | 111.89 ± 57.00 | 12.56 ± 9.57 | 0.006 [†] | 1.31 |
| Shoulder Extension (Degrees) | 47.78 ± 10.79 | 3.89 ± 5.60 | 0.072 | 0.69 |
| Shoulder Abduction (Degrees) | 101.33 ± 47.70 | 10.00 ± 9.63 | 0.016 [†] | 1.04 |
| Shoulder Horizontal Adduction-Abduction (Degrees) | 75.00 ± 42.25 | 24.22 ± 17.62 | 0.005 [†] | 1.37 |
| Elbow Flexion (Degrees) | 114.22 ± 37.82 | 5.89 ± 9.47 | 0.038 [†] | 0.62 |
| Elbow extension (Degrees) | 156 ± 25.31 | 4.56 ± 3.28 | 0.004 [†] | 1.39 |
| SIS-HAND FUNCTION (scores) | 11.4 ± 4.12 | 2.40 ± 3.31 | 0.047 [†] | 0.73 |
| CAHM (%) | 53.39 ± 24.41 | 6.87 ± 12.03 | 0.105 | 1.75 |

Notes: FMA-UE, Fugl-Meyer assessment scale of upper extremity; WMFT-TIME, Wolf Motor Function Test-Time; WMFT-FAS, Wolf Motor Function Test-Functional Ability Scale; SIS-HAND FUNCTION, Stroke Impact Scale-hand function portion; CAHM, Confidence in Arm and Hand Movement; %, percentage; SD, Standard deviation.

*Reach minimal clinically important difference.

[†]*p* < 0.05.

participants felt no burden completing the exercise while the other three participants felt some levels of burden with 3, 10 and 20% respectively.

3.2. Participants' evaluation of Kinect-based UE training: FEASE Questionnaire

Table 3 shows participants' responses and the average scores of the FEASE questionnaire. Eight participants found visual feedback useful and easy to understand. Nine participants agreed that training with Kinect increased their motivation to exercise and they were willing to try new tasks with the paretic arm (mean scores = 4.4). All participants believed that the motions practiced during Kinect training could improve arm function and seven of them reported the exercise as challenging (mean scores = 4.2). Seven participants were not fully satisfied with the current ability of their paretic arm (mean scores = 3.2, neutral), but nine participants believed that their arm ability could be improved, and with continued practice of these arm movements would increase the use of the paretic arm in daily activities.

3.3. Participants' perspective on Kinect-based UE training from the semi-structured interview

Four key themes emerged from the interview data, discussed below.

3.3.1. Past experience with computers and commercially available VR-based games

All participants had used computers before. Seven of them regularly surfed on-line to search for information or check emails. Three participants used computers less often than the others, but still had basic knowledge about how to turn on/off the system and use the mouse. Only three participants had played VR-based games such as tennis and golf using the Nintendo Wii system, and they played these games using the non-paretic arm.

Table 3. Results of feedback efficacy and system evaluation questionnaire (FEASE) at post-training

| Statement | Participant ID | | | | | | | | | | Mean |
|--|----------------|---|---|---|---|---|---|---|---|----|-------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <i>Feedback and speed</i> | | | | | | | | | | | |
| The visual feedback of the exercise is useful and easy to understand | 5 | 3 | 4 | 5 | 5 | 3 | 5 | 4 | 4 | 4 | 4.20 |
| Avatar's speed (1 = too slow; 2 = slow; 3 = just right; 4 = fast; 5 = too fast) | 1 | 3 | 3 | 1 | 1 | 3 | 3 | 3 | 3 | 4 | 2.50* |
| <i>Exercise efficacy</i> | | | | | | | | | | | |
| The exercises are challenging | 3 | 4 | 4 | 3 | 5 | 5 | 3 | 5 | 5 | 5 | 4.20 |
| The exercises practice motions that I believe can improve my arm function ability | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4.80 |
| After training, I am motivated to exercise more often | 5 | 4 | 1 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 4.40 |
| After training, I prefer these exercise to other arm exercises I do at home or at an exercise facility | 4 | 3 | 1 | 3 | 5 | 5 | 1 | 3 | 5 | 4 | 3.45 |
| <i>Self-efficacy</i> | | | | | | | | | | | |
| I am satisfied with the ability of my affected arm at this point in time | 5 | 1 | 2 | 3 | 5 | 4 | 3 | 3 | 2 | 4 | 3.20 |
| The function of my affected arm can improve | 5 | 4 | 5 | 3 | 5 | 5 | 5 | 5 | 4 | 4 | 4.50 |
| Practicing arm movements will increase the use of my affected arm in daily living activities | 5 | 4 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 4.70 |
| Training with the Kinect exercise helped me to be more independent | 5 | 4 | 3 | 3 | 5 | 5 | 5 | 5 | 3 | 4 | 4.20 |
| Training with the Kinect exercise made me willing to try new tasks with my affected arm | 5 | 4 | 3 | 4 | 5 | 5 | 5 | 5 | 4 | 4 | 4.40 |

Notes: 1 = strongly disagree; 2 = disagree/seldom; 3 = neutral/cannot decide 4 = agree and 5 = strongly agree.
 *The only item where 3 is the optimal answer.

3.3.2. Acceptability of the Kinect-based UE training

Figure 1(a) shows the percentage of participants' experience and response to Kinect-based UE training. Words such as "interesting", "enjoyable", and "motivating" were regularly reported during the interview. Nine participants said that the audio and visual aspects of the Kinect-based system provided positive feedback and encouraged them to do more. Seven participants stated that they enjoyed the music and tried to pace arm movements with the beats of the music and followed movement rhythms of trainer avatars. All participants reported that they wanted this system at home and reported they would use it once or twice per day, three to five times a week.

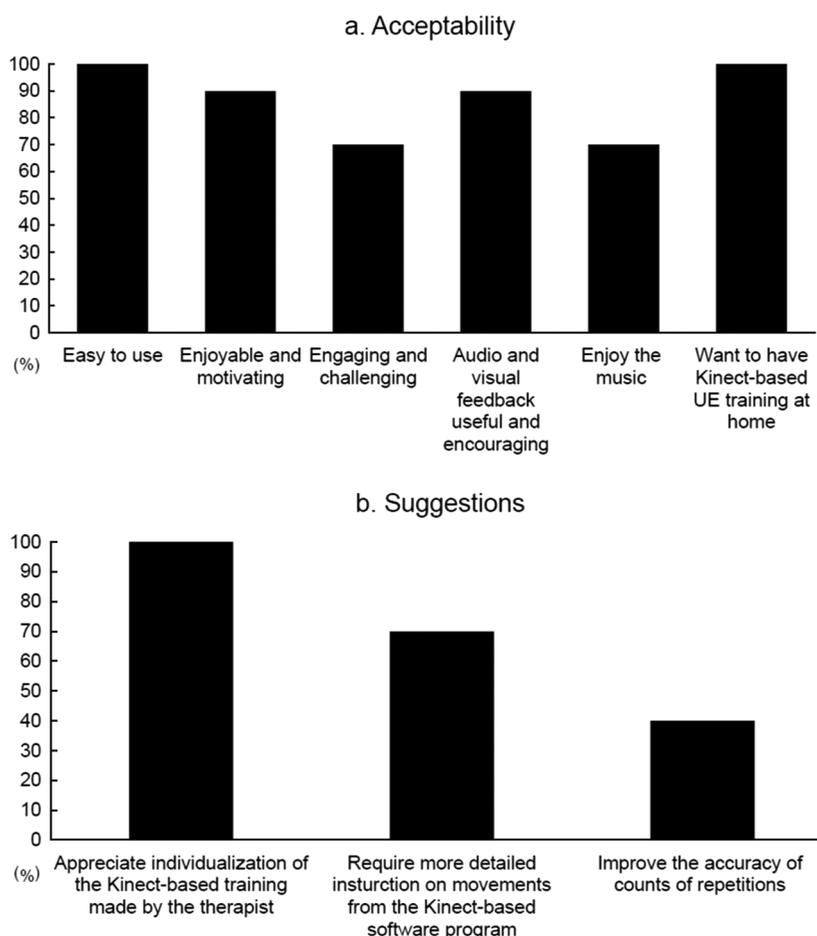
3.3.3. Perceived effectiveness of Kinect-based UE training

Eight participants reported improvements in the paretic arm over the course of training during activities of daily living. Three of them tried new tasks, such as turning on/off the light switch, doing dishes using the paretic arm, and eating crabs using the paretic arm to hold. Others reported endurance changes of the paretic arm such as carrying the grocery bag for a longer time.

3.3.4. Suggestions for Kinect-based UE training

Figure 1(b) shows participants' responses and suggestions regarding Kinect-based UE training. All participants found the instruction and the individualized modification of the Kinect exercises in the first three sessions crucial for performing correct arm motions prior to independent use of the system. They suggested incorporating therapists' instruction and individualized modification into training protocols before use of the system at home. Additional suggestions were to provide detailed instruction on the angle, height and movement range of the paretic arm during the exercise and to improve the accuracy of counting repetitions of the Kinect-based system.

Figure 1. Participants' perspective toward Kinect-based UE training from the semi-structured interview. (a) Above is participants' responses to acceptability of the Kinect-based UE training in percentages (%). (b) Below is participants' suggestions regarding the Kinect-based UE training in percentages (%).



4. Discussion

This study tested the effectiveness of a Kinect-based UE pragmatic training trial with chronic stroke survivors where we included a transition from the clinic to home by providing individualized guidance for the first three sessions. All participants demonstrated the ability to independently use the Kinect system after initial training. We found improvements in the primary outcomes of FMA-UE, WMFT, and AROM of the shoulders and elbows after Kinect-based training. There was also improvement in the hand function portion of SIS, and eight out of ten participants reported increased paretic arm function in daily activities. Most participants found the training enjoyable and easy to follow reporting that the visual and auditory feedback was useful. All participants recognized the importance of the instruction and the individualized modification made by the therapist at the beginning three sessions.

Our study showed that four to five weeks of Kinect-based UE training was able to improve arm function in participants with a broad range of impairment post stroke. Furthermore, these changes achieved levels indicating clinical important differences (Lin et al., 2009; Page, Fulk, & Boyne, 2012). This finding was similar to Sin et al. (2013), who also demonstrated significant and clinically meaningful improvement in FMA-UE scores and AROM where Kinect was used as an additional training to a standard therapy. Their beneficial effects however, may be the result of the combination of the two interventions, rather than Kinect-based training alone as in the present study. Our participants transferred the learned skills into activities of daily living and used the paretic arm in tasks that they were not doing before Kinect-based UE training.

Several factors may contribute to these clinically important improvements. First, the Kinect-based training involved active repetitions of specific arm movements that were individualized to each participant and relevant to daily activities. Compared to commercial games, where the goal is to hit a target, the exercises in this study focused more on continuous practice of individualized movement patterns. This deliberate and repetitive practice may have assisted in recovering more efficient arm movement patterns and led to functional recovery (Bayona, Bitensky, Salter, & Teasell, 2005; Bütetfisch, Hummelsheim, Denzler, & Mauritz, 1995; Jang et al., 2005; Liepert, Bauder, Miltner, Taub, & Weiller, 2000; Woldag & Hummelsheim, 2002). Second, the Kinect-based training provided a novel and motivating experience that facilitated engagement in the training. Participants described the current training as engaging and interesting, and most of them reported that they enjoyed exercising with the system. This high engagement is critical to motor learning which, in turn, could accelerate arm recovery (Krakauer, 2006; Lewis, Woods, Rosie, & McPherson, 2011; Maclean, Pound, Wolfe, & Rudd, 2000). Third, the Kinect-based training offered immediate and augmented visual feedback regarding the correct movement patterns (Holden, 2005). Observation with an intent to imitate the corrected movement patterns may activate the mirror neuron system, assist in generating internal representation of these actions, and therefore may facilitate re-learning of corrected movement patterns (Buccino, Solodkin, & Small, 2006; Garrison, Winstein, & Aziz-Zadeh, 2010; Iacoboni et al., 1999). In addition, there was instant voice feedback to alert participants when they exhibited compensatory trunk and arm motions. Together, these features may have contributed to the effectiveness of Kinect-based UE training and are worthy of consideration when designing VR-based interventions for stroke rehabilitation.

To simulate the transfer from clinic to home use, we provided guidance during Kinect-based UE training at the first three sessions. The parameters of Kinect exercises were individualized to each participant by a physiotherapist. This activity was reported as the most important step expressed by stroke participants during the post-intervention interview. Similarly, a recent qualitative study using Nintendo Wii Sports found that therapists'/administrators' advice was essential for use of computerized VR-based training at home (Wingham, Adie, Turner, Schofield, & Pritchard, 2015). Indeed, one major challenge of a home-based VR system is to provide appropriate training programs according to individual's ability. This is particularly challenging when applying this technology to persons with neurological disorders, such as stroke. Individualization of Kinect exercise by therapists, at least in the first few sessions, appears useful and may have contributed to the success in using Kinect-based UE training in our simulated home environment.

This study demonstrated that stroke survivors with different levels of arm ability could benefit from Kinect-based UE training, however, we did find limited improvement in the participant with the most severe impairments (FMA-UE = 7). The lack of sufficient control of the paretic arm made it difficult for this participant to perform the arm exercise without therapeutic adjustments. Assistive equipment such as an arm support was used to facilitate independent participation in training. These individualized adjustments in the initial sessions can keep the Kinect-based UE training at an effective challenging level, assist in independent practice of movements and therefore facilitate the transition from clinic to home use.

Three limitations of the present study should be noted. First, this study was a single-group design without a control intervention. Our results should be interpreted as showing the effectiveness of Kinect-based UE training compared to no intervention but they do not infer superior effects over other rehabilitation interventions. Second, the tester was not blind to the purpose of this one-cohort study. Third, the sample size was small, although comparable to previous Kinect-based UE rehabilitation studies. However, we found significant and meaningful improvements with mainly large effect sizes (Cohen, 1992). Nevertheless, caution should be taken when generalizing the findings of this study to a wider group of stroke individuals because of the limited sample size. A larger randomized controlled trial would be needed to further confirm findings of this study.

Future studies should also compare Kinect-based rehabilitation between different types of designs to examine which parameters are most helpful for improving arm function. For example, unilateral vs. bilateral arm practice, or different types of feedback, such as knowledge of results vs. knowledge of performance (Molier, Van Asseldonk, Hermens, & Jannink, 2010; Timmermans, Seelen, Willmann, & Kingma, 2009). Detailed information about how and when individualized modification and guidance are given from therapists as well as subjective perspectives of Kinect-based training from stroke survivors should be sought to enhance application of Kinect-based rehabilitation in the home environment (Lequerica & Kortte, 2010; Lewis & Rosie, 2012; Maclean, 2000; Timmermans et al., 2009). Future studies could also compare Kinect-based UE training with other technologies such as the Nintendo Wii to examine comparative and cost effectiveness. In the long-term, the costs of a system like the one used here will be relatively inexpensive and comparable to other home-use virtual reality-based systems such as the Wii system since it requires only a Kinect camera and the software system in addition to a computer.

5. Conclusions

Our study expands current Kinect-based stroke rehabilitation research in that we demonstrated the effectiveness of Kinect-based UE training in a limited sample of stroke survivors with a range of arm ability and in a condition simulating transfer to home use. Compared to previous Kinect-based intervention studies that adopted commercially entertaining games, our training focused more on intensive and repetitive practice of arm movements that are essential to daily activities (Lee, 2013; Sin & Lee, 2013; Taylor et al., 2011). Specifically, we employed a training condition simulating clinic to home transfer environment where therapists' individualized guidance was given only at the first three sessions. The design of the software program, as well as the individualized modification by the therapist seem to be important for facilitating the success of the Kinect-based UE training.

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Author details

Wan-wen Liao¹

E-mail: wliao@som.umaryland.edu

Sandy McCombe Waller¹

E-mail: SMcCombeWaller@som.umaryland.edu

Jill Whittall^{1,2}

E-mail: jwhittall@som.umaryland.edu

¹ Department of Physical Therapy and Rehabilitation Science, School of Medicine, University of Maryland, 100 Penn street, Allied Health Building, Baltimore, MD, USA.

² Faculty of Health Sciences, University of Southampton, Southampton, UK.

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