Kinecting the Moves: The kinematic potential of rehabilitation-specific gaming to inform treatment for hemiparesis

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Abstract: Adapted commercial gaming systems are gaining momentum as cost-effective rehabilitation tools. However, a paucity of accessible rehabilitation-specific systems exist that support bimanual training for individuals with hemiparesis. The objectives of this paper are to describe the development of such a system, and to present preliminary kinematic data analysis obtained from the system to explore its clinical relevance. Two therapy applications for hemiparetic arm rehabilitation were developed and tested, along with a motion tracking application that used two interfaces (PlayStation® Move and Microsoft® Kinect™) for videogame play through a social media application developed for Facebook©. To promote hemiparetic arm use, participants were required to employ bimanual symmetrical hand motions during game play. Data were obtained from two adolescent participants with acquired brain injury and one healthy control, all of whom were part of the usability testing phase of the FEATHERS (Functional Engagement in Assisted Therapy through Exercise Robotics) project. Data from distinct movement trajectories collected during one game session were filtered using described protocols. Total distance moved, range of motion, trunk compensation, and vertical wrist offsets were extracted from kinematic data for therapist interpretation. Clinical observations, video analysis and comparison to a healthy control supported the interpretation of the results. Results showed the system is capable of accommodating participants with large variation in arm function. The kinematic data and analysis algorithms presented may be useful to inform therapists about their patients' performance and progress during the remote monitoring of home-based therapy programs using the system.

Keywords: Serious games, virtual rehabilitation, kinematics, Kinect, hemiparesis, brain injury, rehabilitation, bimanual therapy, motion tracking, social media

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Introduction

The use of commercial gaming systems is gaining momentum in the field of rehabilitation (1). Virtual reality and active video games can increase user engagement and enjoyment in rehabilitation, increasing the potential for enhancing patient outcomes (2-3). Therapeutic gaming may be one treatment tool selected by therapists for individuals with hemiparesis as a means of providing motivating opportunities for repetitive motor practice that encourages specific movement patterns and use of the impaired limb (4-5). Bimanual therapy is an effective approach to reduce impairment and to improve functional ability of the paretic arm (6). However, commercial video games are not designed to consistently optimize the use of both arms simultaneously. Challenges exist, therefore, in the application of these systems to meet the therapeutic needs and physical capacities of different patient populations (7). Accordingly, the development of novel game applications and user interfaces for commercial gaming systems is expanding the potential for the technology to be adapted and integrated for these purposes, both in clinics and in the home.

Motion tracking technology is being used increasingly both as a movement interface in these gaming systems, and as a means of capturing data about participants' kinematic movements during rehabilitation (8-9). The Vicon system (Oxford, UK) (10), the FASTRAK system (League City, TX) (11), and the Microsoft Kinect™ (Redmond, WA) (12) are three examples of this technology. The marker-based Vicon and FASTRAK systems provide higher accuracy compared to the Kinect, however at a higher cost and required expertise, making them unsuitable for most rehabilitation applications. Conversely, the Kinect has demonstrated centimetre-level accuracy, yet high correlations of tracked data with those obtained by marker-based systems (13). These findings, along with its commercial availability, make the Kinect a potential candidate for use in a clinical or home setting for rehabilitation. Furthermore, at this time, no documented guidance exists to translate the Kinect's kinematic data into clinically relevant information that is useful to therapists prescribing gaming interventions.

The FEATHERS (Functional Engagement in Assisted Therapy through Exercise Robotics) project focuses on the development, testing and implementation of rehabilitation-specific interfaces for bimanual therapy, and the extraction of kinematic data to inform therapists monitoring patients' performance and progress. By applying custom algorithms to data collected from the Sony PlayStation Move (Tokyo, Japan) and the Kinect systems, it is possible to determine the total distance moved by the participant, their range of motion (ROM), and the vertical hand offsets for different directional movements. Moreover, the Kinect system is capable of providing data about excessive trunk movements.

The purposes of this paper are therefore: 1) to describe the adaptation of two commercial interfaces (PlayStation Move and Microsoft Kinect) to promote bilateral arm use during social media-based game play; and 2) to share preliminary kinematic data from two participants with hemiparesis using the systems. The analysis of the kinematic data offered by the systems allows for the extraction of clinically relevant information that can be shared with therapists to inform their treatment decisions.

Methods

System Description

In order to use the two motion capture interfaces for the upper limb rehabilitation of individuals with hemiparesis, a computer application called "*FEATHERS Motion*" was developed. The *FEATHERS Motion* application relies on the use of bimanual motions in the frontal plane to control the mouse cursor on a Windows® 7 personal computer. Two motion modes (Visual Symmetry and Point Mirror Symmetry) are available for mapping the hand with the least movement into cursor motion. In Visual Symmetry mode, users are required to move both hands at the same time in the same direction, while in Point Mirror Symmetry Mode, users must move both hands around the circumference of a circle, similar to turning a steering wheel.

A second application, "*FEATHERS Play*", enables users to connect with their therapists and other participants on Facebook to receive recommendations about games from their therapists and to review their game scores. An alternate version of the application was developed for therapists to monitor participants' game scores and to facilitate communication with their patients.

Both applications have been refined based on the results of previous usability testing conducted with rehabilitation professionals (see (14) for details).

Participants

Participants were two male adolescents recruited through therapists at a local rehabilitation centre. Subject 1 was 19 years old and right-hand dominant. He presented with left hemiparesis and increased finger flexor tone following a traumatic brain injury and brachial plexus injury two years prior. Some decreases in both active and passive ROM for shoulder flexion, extension and external rotation persisted at the time of the study. Subject 2 was 13 years old, and left-hand dominant prior to incurring a stroke 14 months before the study. He presented with right hemiparesis, with weakness of the external rotators of the shoulder, no active supination of the forearm and decreased wrist flexor and extensor strength. In addition, a healthy 28-year old right-handed male participated as a control comparison.

Study procedure

Testing was carried out at a local children's rehabilitation centre. Each user test session involved a moderator who provided information about the technology and task requirements, a note taker who recorded observations about interactions with the technology, a caregiver/guardian and a therapist who assisted with instructions, monitored and supported functional interactions based on participants' needs, and recorded clinical observations. All sessions were audio and video-recorded. Research Ethics Board approval was obtained from the University of British Columbia, along with informed consent/assent from participants and a parent/guardian as applicable.

Each participant took part in a 90-minute session during which they were asked to complete a set of tasks to evaluate the ease of use of the system. Participants were introduced to the FEATHERS applications and both motion tracking interfaces, and played "Lucky Pirate" (OUAT Entertainment) in both motion modes using each interface after receiving instructions on the movement and task requirements.

Kinematic data were recorded for both interfaces, i.e., the 3-dimensional (3D) position of the PlayStation Move controllers, and all of the upper body joints using the Microsoft Kinect. Only kinematic data from the Kinect-based system are presented here because of the system's capacity to allow for the analysis of trunk compensation.

Data analysis

The kinematic data for each participant were captured during a game session of approximately three minutes. Joint position data were analyzed for each participant using six joints (wrists, shoulders, shoulder centre, and hip centre). Recommended filter values provided by the Kinect Windows software development kit (SDK) were applied to minimize jitter and to stabilize joint positions over time. To obtain the single session performance results, the data were filtered to remove outliers related to joint occlusions and noise. Video footage was cross-referenced to remove portions of the data in which the participant was not interacting with the system (e.g., receiving instructions, practicing, resting, etc.).

For the data analysis, four performance metrics were chosen: the total distance travelled by each hand, wrist range of motion (ROM), trunk compensation, and hand offsets during vertical movement. For the first two metrics as well as for hand offsets, joint position data at the wrist and hip centre were analyzed; for the analysis of compensation, shoulder and shoulder centre joints were added. These metrics were selected because of their potential for indicating participants' functional abilities and movement quantity and quality. Even though these metrics can be applied to both motion modes (Visual Symmetry and Point Mirror Symmetry), only the Visual Symmetry mode is presented here to serve as an example of the system's capability.

The total distance travelled by the wrists was calculated by measuring all the wrists' horizontal (x-axis) and vertical (y-axis) displacements between consecutive camera frames through the entire duration of the interaction. As most of the wrist movements occurred in the frontal plane, only the X and Y values were used for this calculation. The filtered wrist data were calculated and plotted to obtain the wrist ROM.

In order to extract kinematic information related to the participants' intended direction of motion, all movements in the game session were first categorized into horizontal and vertical segments based on cursor movements. Each segment was then grouped into one of four categories: upward, downward, right and left, based on the direction of the wrist trajectories. Upward trajectories of the shoulders and wrists were plotted to identify any trunk compensation. Finally, three upward movement data sets for each participant were analyzed for vertical hand offsets. During this analysis, the positions of both wrists were compared in the vertical direction to obtain a scalar that indicated the level of vertical asymmetry in the participants' movements. Values were calculated with respect to the paretic side (i.e., a positive value means the non-paretic side was at a higher vertical position).

Results

Total distance travelled in two dimensions

Table 1 summarizes the total distance travelled by the wrists for each participant. Although only movements in the frontal plane were analyzed, 3D data of the wrists will be used in the next study phase in which participants will be required to perform movements with larger variation in depth (z-axis).

[Insert Table 1 about here]

Range of motion

Table 2 shows the ROM of each hand, computed based on the wrist movements of each participant. Figures 1-3 illustrate how the horizontal and vertical ROMs are different for each of the participants, and how each of the participants' hands moved in different areas in front of their bodies. All figures were centred with respect to the median values of the hip centre.

[Insert Table 2 and Figures 1-3 about here]

Trunk compensation

Figures 4 and 5 show one upward movement trajectory for each hemiparetic participant. Shoulder and wrist data are plotted and centred with respect to the median values of the hip centre.

[Insert Figures 4 and 5 about here]

Vertical offsets of both hands in an upward movement

The three upward movement data sets on vertical hand offsets for all three participants are plotted in Figure 6. The vertical wrist offset of Subject 1 ranged from a value close to 0 m to 0.28 m, while for Subject 2, it ranged from -0.04 m to 0.09 m. All offsets shared a similar decreasing trend with respect to motion time.

[Insert Figure 6 about here]

Discussion

This paper presents a novel interface that targets a gap in the commercial gaming field for bimanual training for individuals with hemiparesis, using existing games through a social media platform. With the integration of the Kinect sensor, motion tracking data can be harvested to inform treatment program development and progression by therapists.

With respect to the total distance travelled by the wrists, overall, the values for Subject 1 were closer to the healthy control's results than those of Subject 2. This finding may relate to the shorter and more direct trajectories achieved between targets for Subject 1. This observation may be explained by Subject 1's greater motor ability and the fact that he kept his arms at chest level for most of the interaction. Subject 2, who had the greatest level of impairment, appeared to cover more distance than the other two participants. Video and kinematic data analyses suggest that this might be related to his frequent need to rest his hands in his lap between movements. This effect can be observed in the large values for both left and right vertical distances.

Therapists may find information about the total distance travelled useful, in conjunction with the straightness of the hands' trajectories, in order to assess if the participants' movements are progressing toward more efficient movement patterns. Distance travelled may hold potential as an indicator of the recovery progress of participants in this respect.

In terms of wrist ROM, in the vertical direction for both hemiparetic participants and in the horizontal direction for Subject 1, larger ROM of the non-paretic arm versus the paretic arm was recorded, consistent with their clinical presentation during functional tasks. Dissimilar findings for Subject 2 in the horizontal plane may be explained clinically by his limited control of the paretic side and his tendency to use compensatory trunk movements during play. Given the symmetrical nature of the movement requirements during game play, these data may be valuable to therapists as an indicator of quality of movement and improvement of functional reaching capacity over time, as well as a means of monitoring fatigue of the paretic arm over the course of a treatment session.

Wrist and shoulder trajectories for Subject 2 in Figure 5 showed clear evidence of excessive trunk movement on the right side (19cm and 14cm for right and left shoulder, respectively). This result was verified by video footage, where Subject 2 was observed to employ compensatory movements of the trunk during reaching. Further analysis of the video and visual inspection of the 3D trajectories related to data shown in Figure 5 indicated that Subject 2's left shoulder moved downwards to the left and backwards, while his right shoulder moved upwards to the left and forward. These compensatory movements of the trunk were thought to accommodate for his limited upper limb motor control. No excessive trunk movement was observed in Subject 1's trajectory. Return to pre-injury movement patterns are desired in order to promote recovery and to prevent long-term consequences of compensatory movements, such as decreased range of motion, pain, or learned non-use (15). As a result, data about compensatory movements are important for therapists, particularly in situations, such as remote home-based monitoring, in which clinical observations about these movements may not be possible.

The paretic side for both participants moved in a longer trajectory that was less straight than the unaffected side. The decreasing trend in all vertical offsets with respect to motion time was consistent with the shoulder and wrist trajectory plots, suggesting that the participants were trying to synchronize both of their arms to reach the same vertical position at the end of the motion, as evidenced by both hands stopping close to the same height. Offsets between two corresponding joints during directional movements can provide useful clinical information on motion symmetry – the smaller the offset, the more symmetric the motion. For instance, data about over- or undershooting a target with the paretic arm can provide insights into quality and control of movement; fatigue may be deduced remotely by observing trends in offsets over time. In our example, the calculated vertical offset indicated how symmetric the hands were vertically when the participant was performing a bimanual upward motion; in the future this analysis could be repeated in other directions.

Limitations

Two main limitations existed with respect to data analysis. Specifically, total distance was calculated using data from two dimensions despite depth excursion data being available. This decision was based on the nature of the movements required for the gaming task used during testing; in subsequent phases of the project, 3D data analysis will be become meaningful. In addition, trunk compensation data were analyzed for single movement trajectories; in reality, users perform multiple reaching trajectories during a game session. For these data to be valuable for therapists tracking patients' progress, custom algorithms must include a means of comparing trajectories to known locations over time. A third limitation relates to the accuracy of the Kinect, given that this is an inexpensive, commercially available gaming sensor that is not designed for sub-millimeter accuracy. However, in this study, the Kinect was shown to be a suitable solution for providing therapists with useful information about participants' gross upper limb movements. With the advances of the next generation Kinect sensor, the potential for improved accuracy may further enhance its utility for progress tracking during rehabilitation.

Conclusion

Kinematic analysis of data provided by commercially available motion tracking technology could serve as an additional tool for therapists engaged in rehabilitation, particularly in the context of home-based interventions for which regular feedback about clients' movements are otherwise not available. While system limitations exist relative to the accuracy of gold standard motion tracking technology, this trend data can be used in tandem with clinical observations to identify variations in participants' gross motor movements compared to healthy controls. This paper highlights the type of data that could be provided to therapists about the quality and amount of movement carried out during therapeutic gaming. These results will inform the next design iteration of the interfaces and data processing algorithms of this project. These data analysis principles will be employed in the next phase of the project to provide data to therapists monitoring a 6-month home-based treatment using the developed systems with individuals with hemiparesis.

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Tables and Figures

Table 1. Total distance travelled by the wrists during a single game session

Participant	Left Hand Horizontal (m)	Left Hand Vertical (m)	Right Hand Horizontal (m)	Right Hand Vertical (m)
Control	4.94	6.99	4.11	7.35
Subject 1	*7.04	*8.22	6.07	6.69
Subject 2	8.32	13.85	*9.11	*7.64

Note: *=hemiparetic side

Table 2. Range of motion at the wrists during a single game session

Participant	Left Hand Horizontal (m)	Left Hand Vertical (m)	Right Hand Horizontal (m)	Right Hand Vertical (m)
Control	0.34	0.41	0.28	0.49
Subject 1	*0.40	*0.40	0.58	0.56
Subject 2	0.45	0.60	*0.49	*0.50

Note: *=hemiparetic side

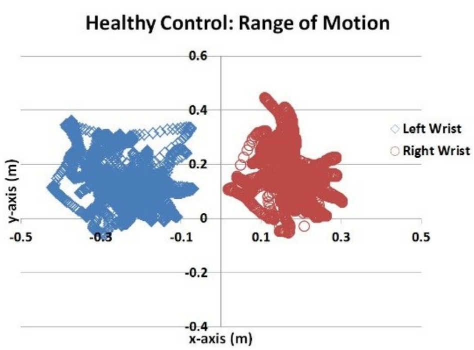

Figure 1. Healthy Control range of motion at the wrists

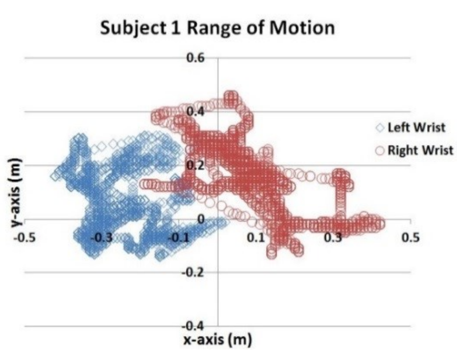

Figure 2. Subject 1 range of motion at the wrists (left hemiparesis)

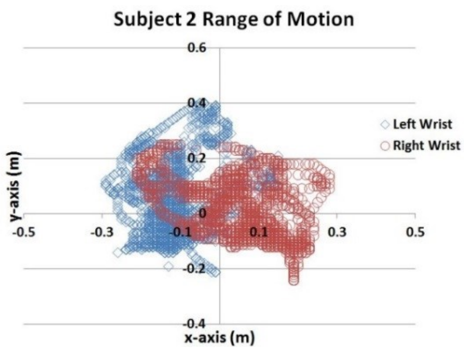

Figure 3. Subject 2 range of motion at the wrists (right hemiparesis)

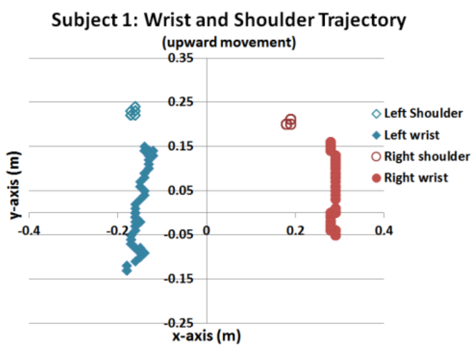

Figure 4. Wrist and shoulder trajectories during a single upward movement by Subject 1 (left hemiparesis)

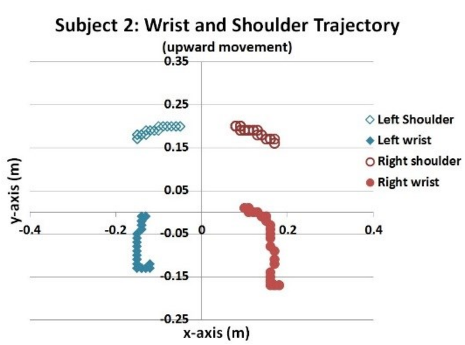

Figure 5. Wrist and shoulder trajectory during a single upward movement by Subject 2 (right hemiparesis)

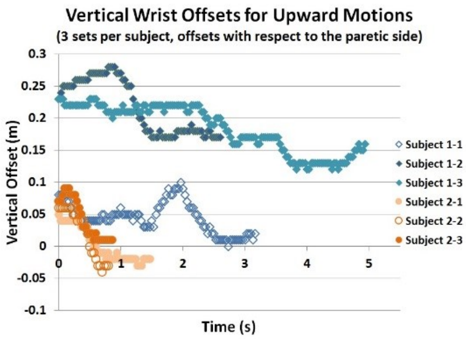

Figure 6. Vertical wrist offsets of three upward movements for each participant