Validity of the Kinect and Myo armband in a serious game for assessing upper limb movement

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Abstract

A cost-effective, easily-accessible neuro-motor rehabilitation solution is proposed that can determine the range of motion and the kinematic ability of participants. A serious game comprising four-scenarios are developed in which the players control an avatar that mirrors the rotations of the upper-limb joints through multi-channel-input devices (Kinect, Myo, FootPedal). Administered functional reach tests (FRT) challenge the player to interact with a 3D-environment while standing or sitting and using the FootPedal which simulates the action of walking whilst body movement is measured concurrently. The FRT's complexity level is adapted using a Monte Carlo Tree Search algorithm which determines a virtual object's position based on the proved ability of the user. Twenty-three volunteers were recruited to play the game in 45-minute sessions. The data show that the system has a more positive impact on players performance and is more motivating than formal therapy. The visual representation of the trajectory of the objects is shown to increase the perception of the participants voluntary/involuntary upper extremity movement, and the results show a comparable inter-session reliability (acceptable-good) over two repeated sessions. A high Pearson correlation demonstrates the validity of using Kinect and Myo devices in assessing upper-limb rehabilitation, and the timing and the clinically relevant movement data have a higher accuracy when the devices are paired.

Keywords: `Kinect v2, Monte Carlo Tree Search (MCTS), Myo Armband, FootPedal`

Highlights

- The applicable agreement between the devices was measured using a two-way ANOVA.

- 3D visualisation and real-time mirrored effects have helped a player's to correct themselves and improved the ROM.

- A comparable inter-session reliability (acceptable to good) $ICC_{2,1} \geq 0.79$ over two repeated sessions was achieved.

- The Pearson correlation between two devices was high ($r \geq 0.84$).

1. Introduction

Stroke, brain injury and multiple sclerosis are the leading causes of most disabilities in adults which result in neuro-motor deficits. This can affect postural control and balance and cause difficulties in independent daily life [13, 18, 23]. Physiopathologic research has demonstrated that such difficulties include utilising hands for timed grasp, holding, buttoning, reaching, balancing or/and walking [27]. It is of vital importance to provide opportunities for patients to relearn or improve basic skills by doing exercises that help them to restore appropriate physical functionality. The recent availability of inexpensive off-the-shelf sensors (such as the Apple iPad, Nintendo Wii, Nintendo DS, Microsoft Kinect and balance board) have opened up new exciting perspectives to assess the practical capabilities for home-based rehabilitation and to improve exercise capacity [37, 9]. These devices have received attention from the academic community in many disciplines including; health, robotics, biomechanics, and engineering [12, 19, 22, 36, 21, 26, 33, 20, 35, 32, 31, 40]. Some of these devices have been used by researchers to develop rehabilitation tools, but they lack sufficient data acquisition capability [28] or are expensive, time-consuming and require extensive technical expertise [2]. The Kinect v2 however is a realtively cheap, easily configurable off-the-shelf device capable of accurately tracking gestures and joint positioning [8]. It detects the position, orientation and angular velocity of a players' 25-joints through use of an infrared emitter and a colour camera which forms part of a skelton tracking system to mirror the location of the player's joints. [25] report that those body parts that are obstructed from the
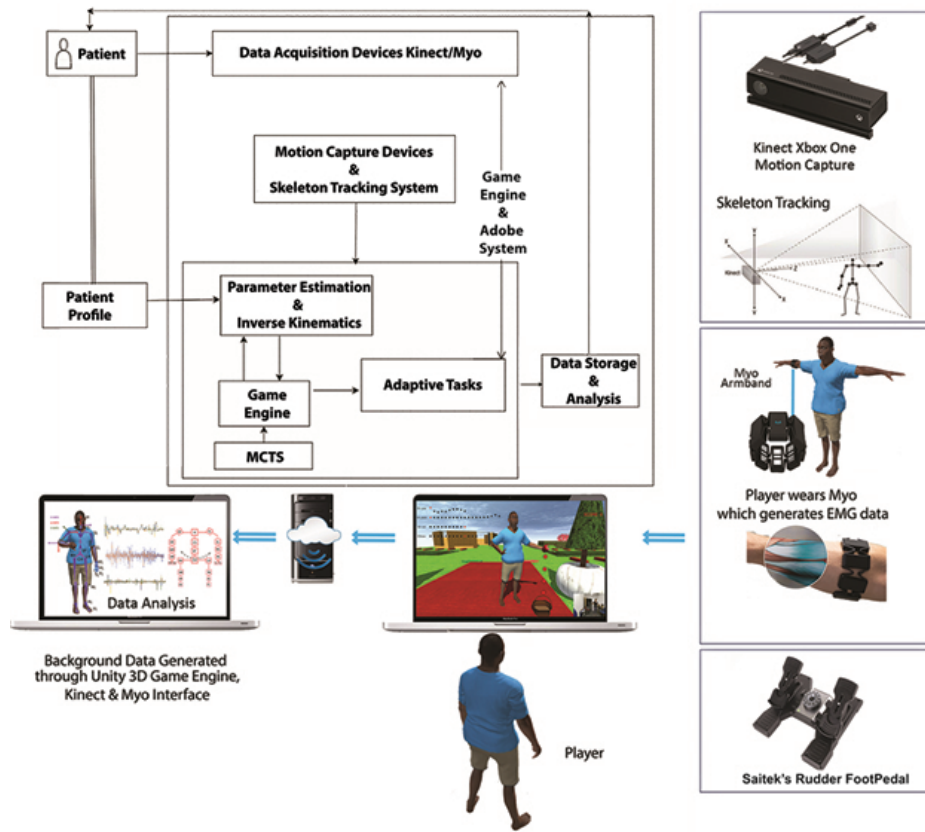
Figure 1: The game's architecture.

Kinect's direct line of vision cannot be tracked, whilst [9, 2, 8] conclude that the Kinect v1 system can accurately measure gross unique characteristics. [4] have conducted a comparitive study on motion tracking between Kinect and the OptiTrack optical systems and their work shows that Kinect can achieve a comparable motion tracking performance. Previous work exclusively using the Kinect in a rehabilitation context includes its use in the recovery of spinal muscular atrophy [5] who report a significant improvement in patient motivation, and [34] who devised a quantitative assessment of exercises performed by trauma brain injury patients. A number of researchers have utilised the Kinect in conjunction with other devices. These (expensive) studies include use of MoCap and treadmill system for rehabilitation and gesture recognition [29] and integration with a multiple camera 3D-motion analysis system [8]. The latter study demonstrated that the Kinect can validly assess postural control in a clinical setting. In the present study we aim to bring a novel solution to the problems related to traditional physiotherapy and rehabilitation by using a cost-effective serious game where the core device is the Kinect v2 but integrated with a Myo armband. The wireless Myo armband (Thalmic Lab)[1] is a motion capture device that collects inputs from the user's skin. The Myo is made of eight medical grade stanless steel electromyography (EMG) sensors that detect the electric impulses in the muscles. The armband is connected via a Bluetooth USB adapter that records/collects real-time data with a high accuracy and precision. The Kinect-Myo apparatus is also linked to a Saitek FootPedal device[2] which is connected to the computer via a USB port and a seated or standing player in order to simulate walking via the avatar; foot resistance is adjustable/configurable according to the required level of difficulty. Use of the FootPedal is reported here solely for information as it will be the subject of future development and is not the focus of the present study. This multi-input system outputs high quality data and provides the convenience of wireless transfer to provide a superior clinical grade source of medical data for muscular performance compared to alternative hardware studies. The players' input is simultaneously transferred into a simulated virtual 3D-park via the Unity game engine with all files and data stored locally on a hard drive. A Monte Carlo Tree Search algorithm (MCTS) generates virtual objects in the 3D-space and adapts game difficulty to the player's ability in real-time. Fig 1 illustrates the architecture, peripherals, and algorithm used to design the system. Four game scenarios are developed; "Fruit-Collection" to grasp/ release virtual fruits in a virtual basket, "Button-Press" to reach/ press virtual buttons

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[1]https://www.myo.com/
[2]http://www.saitek.com/uk/prod/pedals.html

for 3-seconds (the duration reflects an appropriate balance between playability and difficulty), "Sling-Shot" to knock-down virtual boxes and "Fruit-Collection with the FootPedal" to navigate between pre-established key points and collect virtual objects [14]. The frequencies of the entire data collection were normalised to facilitate comparison between Kinect and Myo when continuously estimating and comparing arm orientation. The reliability and accuracy of the devices in measuring functional and clinically relevant movements of the upper limb were also investigated. Use of a FootPedal is not significant to this study and only reported as work in progress for future developments to the game.

2. Methods

2.1. Monte Carlo Tree Search (MCTS)

MCTS is a probabilistic algorithm based on the random simulations of paths taken by an upper limb (combination of joint positions) to grow the tree (path) structure. It uses the "upper-confidence-bound-for-trees" (UCT) selection strategy to pick the highest victory ratio and construct confidence intervals [3, 11, 16, 7]. Fig 2 (a) shows the four-stage algorithm that is broken down into **Selection**, **Expansion**, **Simulation**, and **Backpropagation** and described in detail by [3, 6]. Fig 2 (b) shows a branch of the tree of the rehabilitation game structure represented by a 'right hand' with its child nodes. The algorithm iteratively builds a search tree until a predefined number of evaluations is reached. The search stops and the best performing root-action returned. The next action is chosen according to the stored statistics according to a balance between exploitation and exploration. If the selected action is less promising, it continues exploration. Child nodes are added to grow the tree according to the available satisfactory weighting of actions. A roll-out is performed when a predefined stop criterion is met, the score is backed-up to the root node, and the reward is saved. The pseudocode is presented in Algorithm 1.
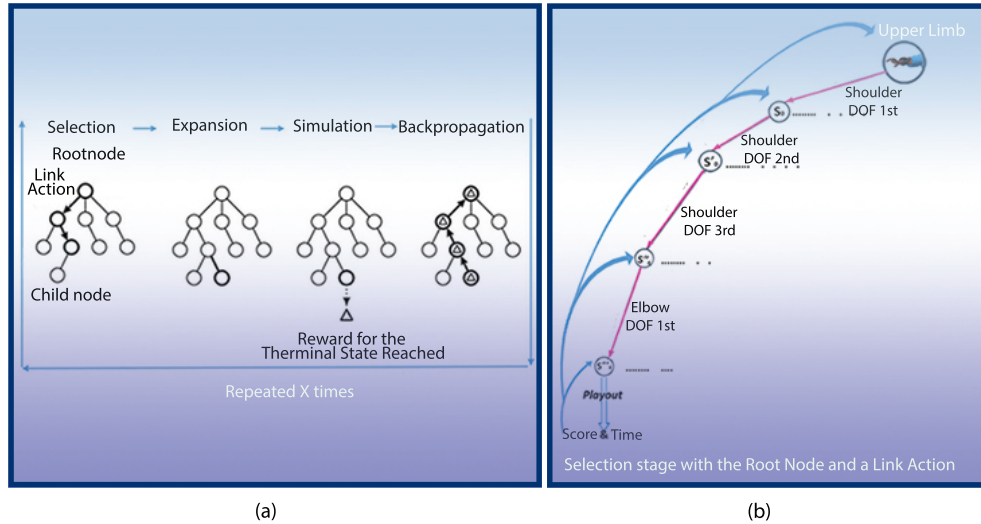

Figure 2: (a)four-stage MCTS algorithmic mechanism. (b) the MCTS algorithm for the right upper limb in the rehabilitation games.

Algorithm 1 Rehabilitation Game Algorithm.

1: **while** $Trial < NumOfTrials$ **do**
2:     $CT \leftarrow RetrieveConfidenceTree(StaticData)$
3:     $Path \leftarrow SelectLeastConfidentPath(CT)$
4:     **for all** $Nodes\ in\ Path$: **do**
5:         $TPos \leftarrow AdjustTargetPosition(Node->Rotation)$
6:     **end for**
7:     $WaitForUserResponse()$
8:     $Confidence = 1 - \frac{ResponseTime}{AllowedTime}$
9:     $PropagateThroughTree(CT, Confidence)$
10: **end while**

2.2. Game Design

In designing the game scenarios, a broad spectrum of rehabilitation exercises were devised using advice obtained through collaboration and consultancy from physiotherapists. The game was adjusted continuously throughout the development process in accordance to the experts' feedback. Fig 4 (a) shows a screenshot of the "Fruit-Collection" game; a 3D-virtual-park with virtual-fruits that are generated based on the MCTS algorithm. The player interacts with fruits by grabbing them (show the palm to the Kinect, open/close the fingers) and then holds on to that fruit and releases it when the reach is above the virtual basket. A valid release condition is flagged to the player by a change from a flashing red to flashing green bottom surface. Once released, gravity pulls the fruit down, it hits/lands in the basket, the score is achieved and recorded, and the fruit disappears [15]. Fig 4 (a) compares the normalised elbow data taken from the Myo and the Kinect playing the "Fruit-Collection" game.
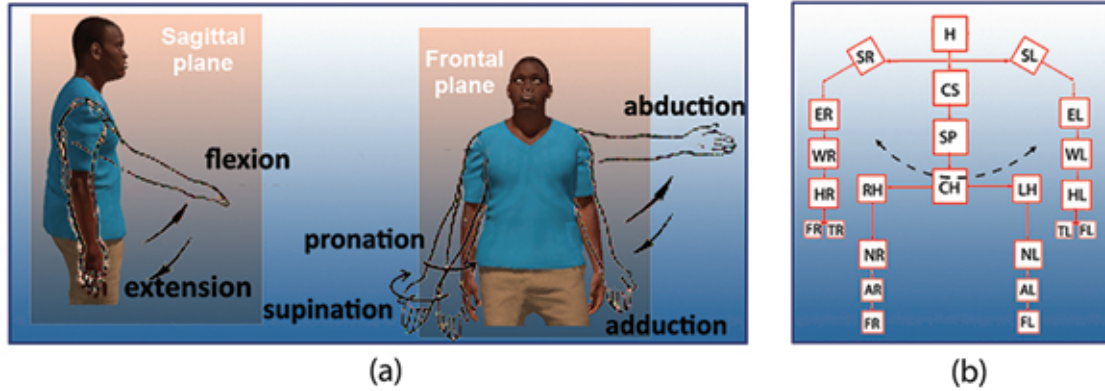

Figure 3: (a) The abduction, adduction, flexion, extension, pronation and supination of the avatar, (b) Stick figure model with Head (H), Central Spine (CS), Spine (SP), Central Hip (CH), Right/Left Shoulder (SR/SL), Elbow (ER/EL), Wrist (WR/WL), Hand (HR/HL), Fingers (FR/FL), Thumb (TR/TL), Hip (RH/LH), knee (NR/NL), Ankle (AR/AL), Foot (FR/FL).
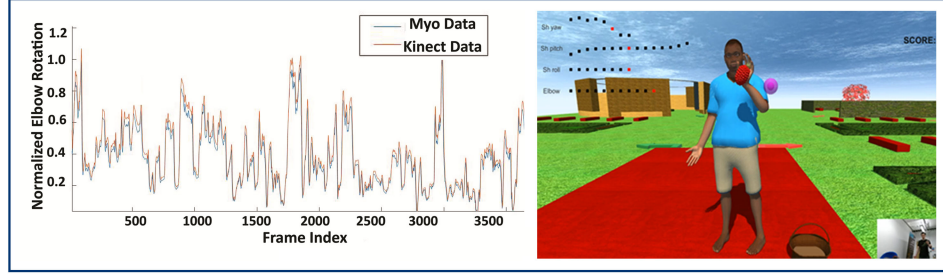
Fig 4 (b) shows a screenshot of the "Button-Press" game. Virtual-buttons are generated in the 3D-park. The player reaches and presses a button steadily for 3-seconds, and a virtual ring with green dots appears (one per second) for visual feedback. The 3-second steadiness is a default value based on our observation throughout the study that no frustration or fatigue was reported by the participants whilst still being challenging to achieve. This sensitivity duration can however be is however be adjusted through the game menu.
Fig 4 (c) illustrates the "Sling-Shot" game. It is made of a virtual-elastic-sling and a virtual ball that is controlled by the player, who pulls the sling with the ball and releases the ball to fly. The sling's reaction force fires the virtual ball into the virtual space. Based on the amount of force applied and the direction pulled the sling's colour changes (from yellow to red) to provide feedback. If the combination of applied forces and the pull directions are appropriate, it hits the virtual boxes and scores.
Fig 4 (d) illustrates the "Fruit-Collection and FootPedal" game where the avatar walks into the park to collect fruits spawned in various locations. Walking is managed by the FootPedal, and the player reaches the highlighted (dark yellow) locations in the virtual world to collect the fruits. When the player reaches a highlighted spot a virtual basket appears that is used to collect the rewards. The same rules are applied for grasp and release actions. The FootPedal algorithm measures the amount of pressure applied to the footrests and determines if the steps are taken in the right order (otherwise the forward movement would not take place). The left/right feet push takes the avatar forward, and toe presses enable turning left/right. The footrest sizes are adjustable and have non-slip materials to hold the foot steady. A left foot pressure is −1, neutral is 0, and a right foot pressure is +1. If the average is negative the left foot is dominant if it is positive the right foot is dominant, and zero means both feet apply equal pressures. Fig 4 (e) plots the trajectory of the FootPedal taken from a healthy subject. It shows that the wave oscillates symmetrically around zero and the mean is zero.

2.3. Subjects

Twenty-three participants volunteered for this study (approved by the researchers' affiliated institutional Research Ethics Committee). Of this cohort 10 healthy subjects (with no known motor defects) were selected to form two Control Groups (CG:5 males, 5 females); 2 participants were post-stroke (PS: 2 males); 2 participants had Traumatic Brain Injury (TBI: 1 male, 1 female) and 9 participants had multiple sclerosis (MS: 3 male, 6 female). The cohort had mean age of 37 (range is
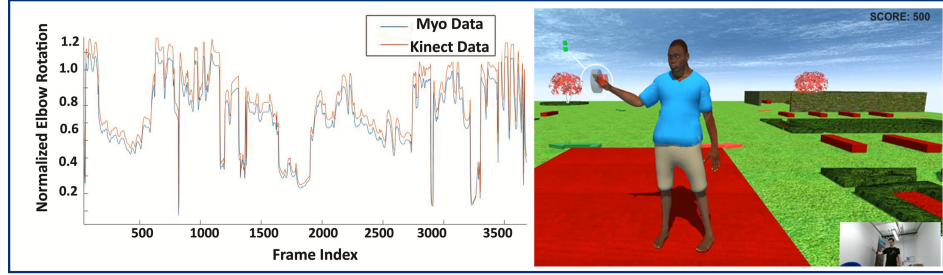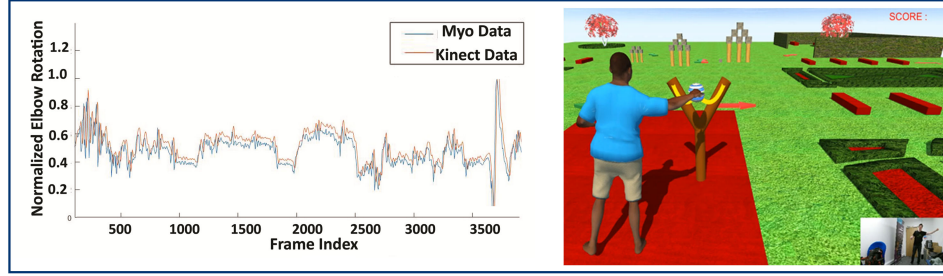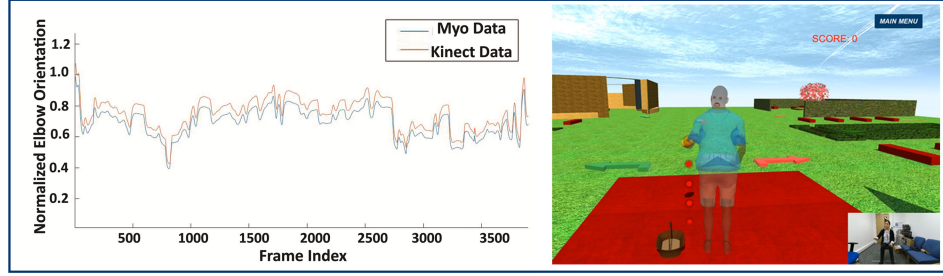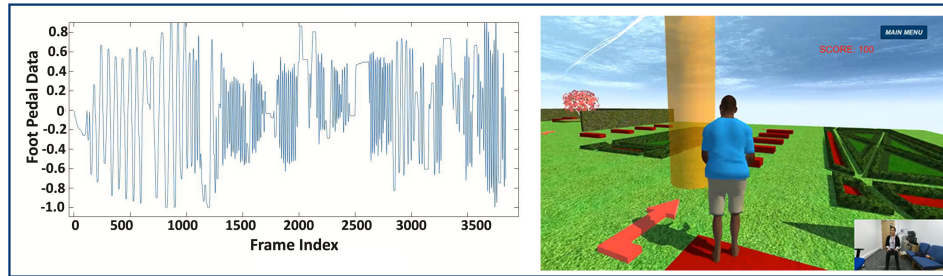
Figure 4: Screen shots of the game scenarios (a) the "Fruit-Collection" game, (b) the "Button-Press" game, (c) the "Sling-Shot" game (d) the "Fruit-Collection-FootPedal" game. All the games were played by CGs. The forearm data were taken by the Kinect and Myo devices; the orientation was normalised. (e) The "Fruit-Collection-FootPedal" with a CG playing the game using the FootPedal device to simulate the avatars' walking.

25−64 years). In preparation for game play a Myo armband was located on the participant's arm above and below the elbow joint. To simplify the comparison of the two systems, the range of motions (ROM) and two-dimensional kinematics of the sagittal and frontal planes were considered where appropriate. The mean ROM and timing were collected based on the frames per second. Subjects were also equipped with the FootPedal as required by the game.

2.4. Materials and data collection

A 3D-avatar was designed with the skeleton joints using Fuse and Mixamo animation software[3]. Before data collection, a camera was placed on a tripod at 1.5 *m* above the floor to track timing and record players activities from behind. The Kinect was placed on a stand located on top of a 0.9 *m* Curved-Ultra-Wide screen. The players performed the exercises in sit or stand positions within 1.5−2.0 m from the screen. Movements in the games are the combination of abduction/adduction, flexion/extension, pronation/supination, shown in Fig 3 (a). The timing is measured based on wrist joint orientation for a proxy measure of functional reach tests. The Kinect calibration was done via the skeleton tracking system with slight modification to capture pronation/supination through wrist joint orientation. The associated algorithm adapts the avatars' dimension to each player's physical proportions. The Myo data was obtained using Samy-Kamkars-myo-osc application[4] with some modification to access the raw EMG data. The joint coordinate systems, linear/angular velocity, and orientations were collected from the devices anatomical landmarks [39]. The orientation and rotation of joints are calculated based on the pitch (rotation about the Kinects' x-axis), yaw (rotation about the y-axis) and roll (rotation about the z-axis). Thus the orientations are determined based on the parent joints and the supporting joints depicted in Fig. 3 (b).
Data were averaged from the Myo light emitting diode (LED) light positioned above and below the elbow joint facing the same direction. The Myo armband device streams the accelerometer, gyroscope and magnetometer data with nine degrees of freedom (DOF) compriding a three-axis accelerometer, a three-axis gyroscope and a three-axis magnetometer. The gyroscope measures angular velocities which can be integrated to obtain the orientation, however this method accumulates an exponential error over time so that in this case the gyroscope can only offer an estimation of the attitude. To mitigate this effect the gyroscope data must be adjusted by the accelerometer and magnetometer to measure the orientation of a wearer's arm and hand gestures [24]. The Myo is made of eight medical grade stainless steel EMG sensors that detect the electric impulses in the muscles. The armband is connected via a Bluetooth USB adapter that records/collects real-time data with high accuracy and precision.
Apart from the rules of the game no other particular instruction was given. The type of the game, the initial difficulty level, the number of trials and timing were configurable via the main menu. The games were developed based on the requirements of compatible modules execution treatment, repetition of tasks, progressive assessment, and considering the needs and viewpoints of a number of involved stakeholders.

2.5. Data processing and statistical analysis

Anatomical frames and associated joints are illustrated in Fig 3 (b). The joints are defined by a single point. SR/SL (Shoulder Right/Left), ER/EL (Elbow Right/Left), WR/WL (Wrist Right/Left), FR/FL (Fingers), TR/TL (Thumb). A hand's angle is measured from the WR/WL to FR/FL and TR/TL. The shoulder angle is defined by the SR/SL and the SP (Spine) line that connects CS (Central Spine) to the CH (Central Hip). At rest, the shoulders are perpendicular to the CS, SP and CH and the neck is aligned with the SP line.
Muscle signals were collected by the Myo armband. To increase the fidelity of the data the maximum amount of noise was filtered using a fifth-order FIR smoothing Savitzky-Golay filter (Signal Processing Toolbox^{TM}) in Matlab [10, 38]. The normalised original and filtered EMG data are illustrated in Fig 5. It compares the data taken from a healthy subject Fig 5 (a) with a post-stroke subject Fig 5 (b) while both were playing the "Fruit-Collection" game. The oscillation of the healthy subjects' muscle signals shows the muscle activity while collecting the fruit in Fig 5 (a). Fig 5 (b) shows the signals occasionally reach a high value and then drops due to patients' muscle fatigue. The ROMs and the kinematic mean were calculated for statistical analysis using the SPSS 24 package. The average bias between the devices was determined using two-sided t-tests over the repeated measurements. Normality tests were conducted to measure the significant differences between the means for different sessions, games and groups. In particular, a Shapiro-Wilk's normality test was calculated [30].
Visual inspection of histograms and normal Q-plots were also performed. The relative agreement between the sensor devices was measured using Pearson's correlation. The absolute accuracy was determined for sessions 1 and 2 using intra-class correlation coefficients ($ICC_{2,1}$) based on a two-way ANOVA [1]. Angular variation was assessed using limits of agreement

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[3]https://www.mixamo.com/fuse
[4]https://github.com/samyk/myo-osc

Table 1: The results of the Kinect and Myo for all games with the average ROM that are taken from CG and patients, separately.

Game	*Session* 1		*Session* 2							
Average RoM °	*Kinect* (K_1)	*Myo* (M_1)	*Kinect* (K_2)	*Myo* (M_2)	*Bias* ($K_1 - M_1$)	*r*	$ICC_{2,1}$	*LoA*	*P-Value*	CV_E
Fruit-Collection										
CG (n=10)	229(12)	224 (8)	228(9)	221 (8)	4.6	0.94	0.87	0.22	0.086	4.2
Patients (n=13)	131(13)	127(10)	133(10)	127(9)	5.6	0.90	0.81	0.17	0.071	3.7
Button-Press										
CG (n=10)	237(15)	232(10)	234(14)	233 (9)	4.4	0.96	0.88	0.16	0.074	1.4
Patients (n=13)	122(12)	118(8)	125(12)	121(11)	3.5	0.93	0.86	0.13	0.146	2.6
Sling-Shot										
CG (n=10)	191(10)	189(6)	193(11)	187(5)	1.7	0.84	0.84	0.19	0.066	1.6
Patients (n=13)	106(8)	103(7)	113(6)	99(9)	2.8	0.87	0.85	0.29	0.093	3.1
Fruit-Collection with FootPedal										
CG (n=10)	242(16)	239(13)	244(15)	235(11)	2.4	0.84	0.79	0.24	0.007	4.5
Patients (n=13)	186(15)	184(12)	189(13)	192(13)	3.1	0.89	0.80	0.28	0.004	5.5

values: *mean value* (*S.D. value*), Pearson's paired samples correlation (r), intra-class correlation coefficient ($ICC_{2,1}$(95%), type 2, 1), Limit of Agreement ($LoA_{95\%}$), Coefficient of Variation Error (CV_E).
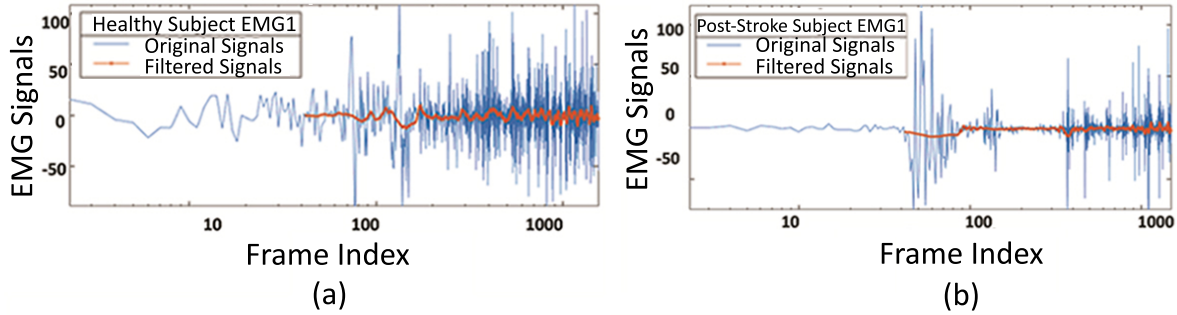

Figure 5: Normalized original and Savitzky-Golay filtered EMG1 signals of a healthy subject (a) compared to a post stroke subject (b) taken from the Myo.

analysis (LoA) with Bland-Altman plots [1, 17]. The coefficients of change of the error (CV_E) [2] were determined to assess angular discrepancies. Hierarchical regressions were performed to guide interpretation and calculation of the significant predictor using *P-Value*.

3. Results and discussion

Analysis of data for CG and experimental group participants were conducted separately and tabulated in Table 1. Bland and Altman plots show that there is no significant bias between the data taken from different games. The average ROM and standard deviation (SD) differences between various groups are due to the limited range of motion of patients compared to the CG and is expected. The timing measurement data and motion of clinically relevant functional movements taken from the Kinect, Myo and also camera footage data are comparable. The reliability $ICC_{2,1}$ is in a range from moderate to good [0.79, 0.88]. The results from the Kinect relate strongly to those obtained from the Myo with a high Pearson correlation ($r > 0.84$). However, intra-session reliability discloses some discrepancy in two devices' capturing the grasp and release actions when the joints are covered by other body parts and not detected by the Kinect. Root mean square error (RMSE) of the Kinect intra-sessions were 11° and 9° for session one and session two respectively. In all cases the values measured by Kinect were overestimated compared to the Myo. The Bland Altman method was used to calculate the mean difference between the measurement of the two devices with 95% limits of agreements (LoAs) above 10%. There was no significant inter-session differences in ROM and the *P-Value* is > 0.05 apart from the "Fruit-Collection-with-FootPedal" game. The CV_E for ROM is in the range of 1.4−5.5 for all the games. Comparison of the camera footage with the Kinect's data showed that if players show the palm to the Kinect device while grasping, releasing or collecting virtual objects, Kinect measures and

detects real-time data with a negligible error. Some occasional delays (mismeasurements) were detected with an error of less than 2.7%.

4. Conclusion

The rehabilitation serious game is a feasible and safe system that could be used to enhance upper extremity limb function in patients with motor impairment. This system is developed to help patients to improve motor limitations and inspire physical rehabilitation. Our results suggest that low-cost home-based devices (Kinect, Myo, and also FootPedal) can accurately measure the timing of movement repetition, Kinematic activity, and ROM. This arrangement can facilitate an inexpensive and home-based assessment and treatment strategy. The statistical analysis has shown a significant improvement in participant performance throughout the trial period, reflected in response times and range of motion. Overall, the results of the current study are encouraging for the next generation of rehabilitation games for gait and balance. All participants with motor impairment showed high interest and engagement during the activities. The players demonstrated the positive feeling and improved moods while playing the game and afterwards because of the scores they achieved. Activities were transferred to the 3D world via the Kinect and FootPedal, and the Myo armband was used for validity and correcting the hand's pronation and supination. The activities seem to have helped the patients to gain a significant benefit by enabling the players to interact with virtual objects without requiring any head-mounted display. It enables them to achieve visual and real-time feedback on the screen. The designed algorithms allow data to be collected and transferred into the avatar. The MCTS configuration algorithm monitors and progressively corrects the abnormalities of the upper limb kinematic movement by expanding the tree.

Overall there is some bias between the calculated ROM by the Kinect and Myo armband. That is, the Kinect has slightly overestimated the ROM values compared to the Myo device. This is because the armband's calculation is based on the peripheral measurements whereas the Kinect tracks single and central joint positions. Although the differences exist, the applicable agreement was good. In this study, the Kinect's inherent inaccuracy with hand gestures is resolved when the player interacted with virtual objects through hand's palm and finger's open/closing gesture. The study indicates that the Myo can be coupled with the Kinect to detect and track hand gestures with high accuracy, and the Kinect skeletal model's limitation for assessment and data conveyance of hand's pronation and supination can be corrected through the Myo gesture control armband. This study suggests that players could use the Kinect as the only single device to interact with the game and perform the rehabilitation activities. It also can be used in conjunction with the FootPedal without using Myo armband.

The results showed a comparable inter-session reliability (acceptable to good) $ICC_{2,1} \geq 0.79$ over two repeated sessions. The Pearson correlation ($r \geq 0.84$) was high enough to determine the validity and reliability of using Kinect and Myo devices in assessing the clinically relevant movement of the upper limbs. Players reported that the 3D visualisation technique combined with the real-time mirrored and visual feedback helped them to correct themselves as well as improve their ROM. They stated that training the physical functions through the system was stimulating, exciting and they could translate the skills learned in such therapy-like activities to everyday life.

Acknowledgement

Conflict of Interest

None.

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