

# Evaluating the Microsoft Kinect for use in upper extremity rehabilitation following stroke as a commercial off the shelf gaming system

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## ABSTRACT

Motion controlled video games have been shown to have a positive effect for physical rehabilitation on the upper extremity in stroke survivors when combined with conventional physical therapy. While much research in this area has worked with bespoke systems and games, some research has been done into using commercial off the shelf gaming systems (COTS) for use in upper extremity stroke rehabilitation. As COTS systems are designed to be used in the home they offer the possibility of providing survivors with low cost systems that they can use to carry out rehabilitation at home. The Microsoft Kinect for the Xbox360 is a multimodal gaming peripheral used to drive a full body skeletal pose estimation system. This allows users to interact with games using bodily motions and gestures. Unlike other current motion controlled gaming systems the Kinect is marker-less so does not require the user to hold or wear any peripherals. A list of important joint motions and movement synergies were identified by looking at leading stroke motor function tests for the upper limb. These have been verified by working with Occupational Therapists. A study group of Occupational and Physiotherapists were asked to record their experience of playing three Kinect mini-games from the Kinect Sports title and evaluate them with respect to their motor function requirements and exertion for each identified joint motion. Quality information was also gathered relating to the perceived usability and safety issues that could arise by presenting the device to a stroke survivor. Kinect provides opportunities for gross arm movement exercise, while the requirement for highly raised arm movements will present a potential barrier for stroke users. Fine motor control movements of the hand and fingers are not tracked sufficiently for effective rehabilitation of the hand. A probable risk of falling while using the Kinect, and potential injury from overexerting the impaired limb while playing existing games were also identified. We conclude that as the experience have been designed for able bodied users the games present significant barriers for using Kinect as a COTS system for stroke rehabilitation.

## 1. INTRODUCTION

Stroke is the third most common disease in the UK with over 100,000 cases annually (Bupa, 2011). Stroke is also the leading cause for long term disability (Adamson et al, 2004). The cost of treatment and dealing with the long term disabilities afterwards is estimated to cost the UK economy £8.9 billion per year (Saka et al, 2009). Impaired arm function is a common effect of a stroke seen in around 70% of stroke cases, 40% of patients will have a completely non-functioning arm (Robinson, 2009). Rehabilitation of the impaired limb is key to helping the stroke survivor regain independence. By allowing more stroke survivors to live independently the costs of providing disabled services and care can be reduced.

Physical rehabilitation is concerned with helping stroke survivors to regain control and coordination of the impaired upper limb. This involves direct contact with physical and occupational therapists to help the survivor develop and perform a set of exercises designed to help regain control in the upper extremity. Physical rehabilitation in this way can be limited by the therapist's availability; giving survivors more opportunity for rehabilitation increases the expected recovery (Robinson, 2009). Following discharge from hospital the survivor may be required to travel to outpatient facilities for rehabilitation; this can be problematic for survivors with poor

mobility (common following stroke) or who live in remote areas. The sudden and often unexpected stroke will have a significant effect on the survivor's life, making tasks that were once easy extremely difficult. It is therefore unsurprising that depression is common amongst stroke survivors. It is important that the survivor remains motivated and engaged with their rehabilitation especially in the early stages when the expected recovery amount is at its maximum (Wade et al, 1985).

Motion controlled video games have been shown to have a positive effect on physical rehabilitation of the upper extremity in stroke survivors when combined with conventional physical therapy (Baranowski et al, 2008) (Burke et al, 2008) (Burke et al, 2009). These games consist of an input method that requires movement of the upper extremity causing the player to exercise the impaired limb whilst playing the game. The game itself provides a motivational context that is fun and engaging for the player to interact with (Burton et al, 2011). While much research in this area has worked with bespoke systems and games, some research has been done into using commercial off the shelf gaming systems (COTS) for use in upper extremity stroke rehabilitation. As COTS systems are designed to be used in the home they offer the possibility of providing survivors with low cost systems that they can use to carry out rehabilitation at home (Lang et al, 2009). This could allow survivors to exercise at a level they are comfortable with, independent of physical or occupational therapists. It also offers a valuable opportunity to survivors who are unable to frequently travel to outpatient centres to engage with rehabilitation activity. Low cost independent rehabilitation solutions may provide a cost effective way for long term rehabilitation which is currently limited by therapist resources (Moeslund et al, 2006) (Dam et al, 1993).

Historically the literature relating to COTS gaming systems for use in stroke rehabilitation has focused on two systems, the Playstation EyeToy and the Nintendo Wii. More recently however, following the launch of the Kinect system in late 2010, there has been a surge of interest in the investigation of Microsoft Kinect and the role it can offer in this context.

The PlayStation EyeToy is a small camera that attaches to the PlayStation 2 gaming system. Functionally it is equivalent to a low cost USB web camera. The device outputs a low resolution colour image. The system then looks for any differences in colour at each pixel over time (between captured frames) to detect any motion at that pixel's location. As the system only looks for motion it is unable to distinguish between the player's movement and any background object. The system does not implement any pose tracking, so is unaware of the player's actual pose or position. To account for this the player is usually asked to stand or sit in a fixed position and use their arms to create the necessary motions. Rand et al (2004) tracked the scores and enjoyment of a group of stroke survivors and a group of healthy elderly users while playing several EyeToy games. Comparing the results showed that both groups found the experience enjoyable and highly motivating. However the stroke group had significantly lower game scores, this can be accounted for by the stroke group reporting fatigue in the impaired limb, preventing them from playing as effectively. It is mentioned that the option to control the speed and difficulty of the games is not present but in this context would be desirable. Yavuzer et al (2008) reported a controlled, assessor blinded trial over four weeks where one group of stroke survivors took part in treatment using the EyeToy. The control group spent the same amount of time observing the game but not partaking. At the end of the four week trial the EyeToy group scored significantly higher when measured with the functional independence measure (FIM).

The Nintendo Wii uses a handheld controller device that can detect its position relative to a sensor bar mounted on the display device and the acceleration force on the controller. Like the EyeToy, the Wii is not able to perform body pose estimation as it can only gather positional information of the controller device. For most games this is assumed to be in the user's hand so can therefore be used to determine hand position. Joo et al (2010) found a slight increase in Fugl-Mayer assessment scores following two weeks of physical therapy using the Nintendo Wii. All subjects found the games enjoyable or very enjoyable. Problems were encountered during the study as some subjects had trouble holding the Wii controller due to poor hand motor control, therefore a custom strap was used to allow the user to 'wear' the controller rather than hold it. Saposnik et al (2010) compares using the Wii to conventional recreational therapy, finding that the Wii offers significant improvement in motor functions measured with the Wolf motor function test. Mouawad et al (2011) also found similar positive results.

The Microsoft Kinect for the Xbox360 is a multimodal gaming peripheral. Its primary input method is a novel low cost ranging (depth) camera that is used to drive a full body skeletal pose estimation system. This allows users to interact with games using bodily motions and gestures. Unlike other current motion controlled gaming systems the Kinect is marker-less so does not require the user to hold or wear any peripherals. The ranging camera allows position estimation in three dimensions allowing complex body poses to be tracked. The accuracy and consistency of the Kinect sensor has been evaluated both in terms of its ability to measure the position of objects (Dutta, 2012) (Shires et al, 2013) and upper body joint rotations (Nixon et al, 2013) These studies suggest that it performs very well. It is however important to acknowledge that under certain circumstances use of the peripheral can be problematic. Some of these limitations are inherently a property of the

technology itself. The use of projected infra-red light precludes the use of the sensor in areas of bright natural sunlight and being camera based, occlusion is a big issue, particularly where the hand or arm pose is unconventional due to a disability.

Lange et al (2011) utilised Kinect in a trial for balance training of adults with neurological injury. This study highlighted the difficulty of achieving the “calibration pose” necessary for the skeletal tracking to initialise properly. Of the twenty participants in this study eight were unable to achieve this pose and the remaining twelve required the assistance of a clinician to manipulate the upper limb into a position suitable for calibration. Pastor et al (2012) also noted the problems with supporting the weight of an impaired upper limb, utilising the Kinect in a downward pointing manner so that a table top could provide support. These studies were based upon bespoke software solutions, the current crop of COTS games have the added drawback of also requiring the player to stand while playing, further exacerbating the potential usability issues associated with using the system and raising further questions about whether it has any potential as a COTS device for home rehabilitation. However the study conducted by Chang et al (2011) concluded very favourably in terms of the utility of the device, noting a significant improvement in motor function as well as recording high levels of motivation and recommending further. In this paper we present our findings from a study to evaluate the Kinect for safety and suitability as a COTS gaming system for stroke rehabilitation. The study also sought to identify areas that a bespoke system based upon Kinect hardware could improve upon, thereby enhancing the rehabilitation possibilities beyond those available within existing commercial titles. The study’s focus was on identifying exercises of interest to upper extremity rehabilitation that are encouraged and facilitated by the system. Full upper extremity rehabilitation requires multiple exercises across a number of joints in the upper extremity. It is important to identify which regions the Kinect is effective at exercising so that its potential as a tool for rehabilitation can be assessed, as well as evaluating the usability of the Kinect device within the physical limitations of a stroke user group. The Kinect system is a full body skeletal tracking system. Games designed for the Kinect are built with able bodied users in mind, therefore as noted by Lange et al (2011) only a subset of available games, or game elements may be usable by a stroke user group with limited physical capabilities.

Safety concerns surrounding usage of the Kinect with a stroke user group were also explored. Stroke survivors with upper extremity deficits commonly have accompanying lower extremity problems, affecting balance and mobility. This can put the stroke survivor at a greater risk of falling. Therapists were asked to assess the presented games to identify if they would put a stroke user at a risk of falling. They were also asked to assess if the Kinect encourages exercises that could have a negative effect on the stroke survivor’s recovery.

As Xbox Kinect has over 140 games from first and third party developers only a small number of these could be included into the study due to limited resources and practicality of the study duration. Potential games were examined against the following criteria:

- Short experiences that a user is able to learn and play quickly are desirable considering the time constraints of the study.
- A complete round of a game should take no more than a few minutes to complete.
- The game must provide adequate instructions for a non-gamer to easily understand and play.
- The game must remain playable for a user with a low level of physical ability.

Using these constraints the game ‘Kinect Sports’ was selected. It is perhaps interesting to note that “sports” was a theme requested by participants in the Lange et al study (2011). Kinect Sports (figure 1) is a series of mini games based on real world sporting activities. As such the rules of the games are easy to learn even to non-gamers as they match the real world counterparts. The mini game format allows short game experiences to be played quickly and repeatedly without spending a significant amount of time operating menu systems. From a selection of six mini games two were selected, Bowling and Table Tennis. These were chosen in order to compare a game that requires the user to react in a limited time (Table tennis) with one where the user is given time to cognitively process and plan the activity (Bowling).

## 2. RESEARCH DESIGN

The study was conducted over several repeated sessions with different occupational therapists. Therapists were allowed to participate individually or in pairs. When in pairs each participant was required to play at least one round of each game individually, while the other observed. Individual participants would watch a demonstration round provided by the session conductor. This was designed to allow participating therapists to observe the system from a first and third hand perspective.



**Figure 1.** *Kinect Sports for the Xbox360.* [Rare, 2014].

At the beginning of each session the occupational therapists were given a brief demonstration of the Kinect system by an experienced user leading the session. The session conductor demonstrated how to start the Kinect system, navigate to the first game to play, start the game and give a brief demonstration of how to play the game. The system was then restarted and each occupational therapist in turn was asked to perform the start-up steps and play the game for several minutes including at least one full round of the game. After each occupational therapist had a chance to use the system and experience the game they were presented with a questionnaire to gather feedback from their experience. Participants were allowed to continue playing the game during the questionnaire. This process was repeated for each of the two mini games.

### 2.1 Population

The purpose of this study is to primarily evaluate if the Kinect is safe for use with a stroke group. Therefore no stroke survivors were involved at any stage of this study. The study population will consist of qualified occupational and physical therapists with experience of working with a stroke population. Six participants were recruited for the study. All six participants completed the study.

### 2.2 Data Collection

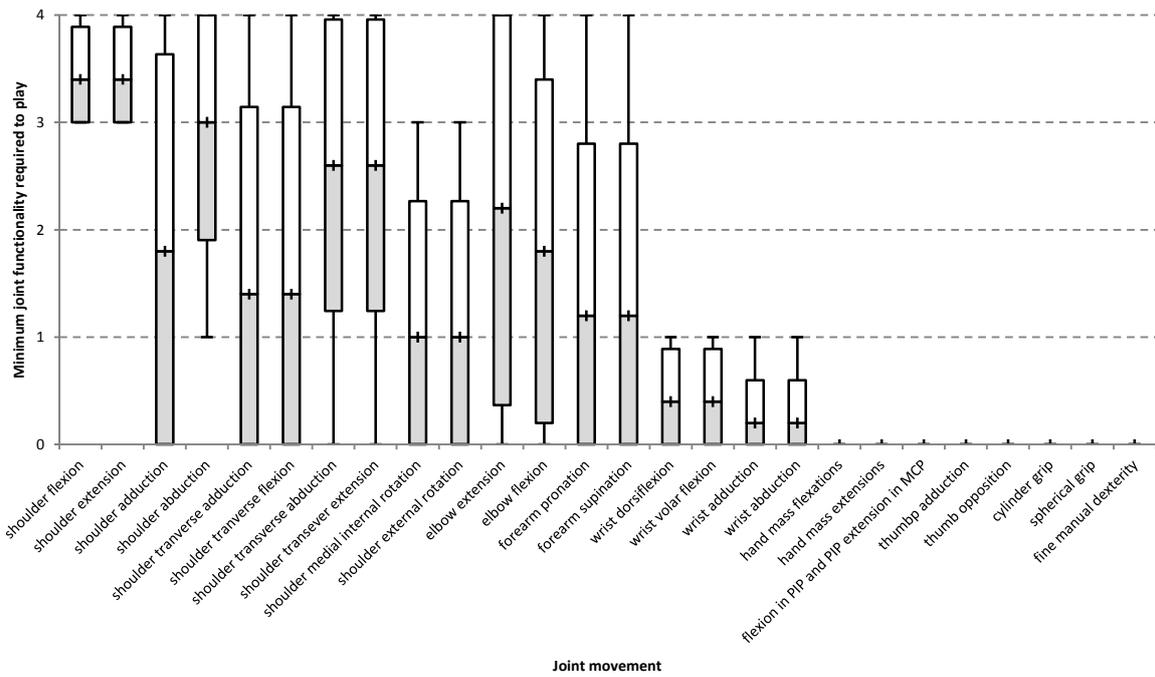
Data was collected by questionnaires completed by the participants. The questionnaire asked participants to rate the minimum joints functionality required at each joint needed to meaningfully participate in the game, how exerting the exercise on each joint was during play and how much they felt the game encouraged them to use individual joint movements.

Participants were also invited to discuss their experience of playing each game. They were asked to focus on any potential safety issues they could foresee when presenting the Kinect system to a stroke population.

## 3. RESULTS

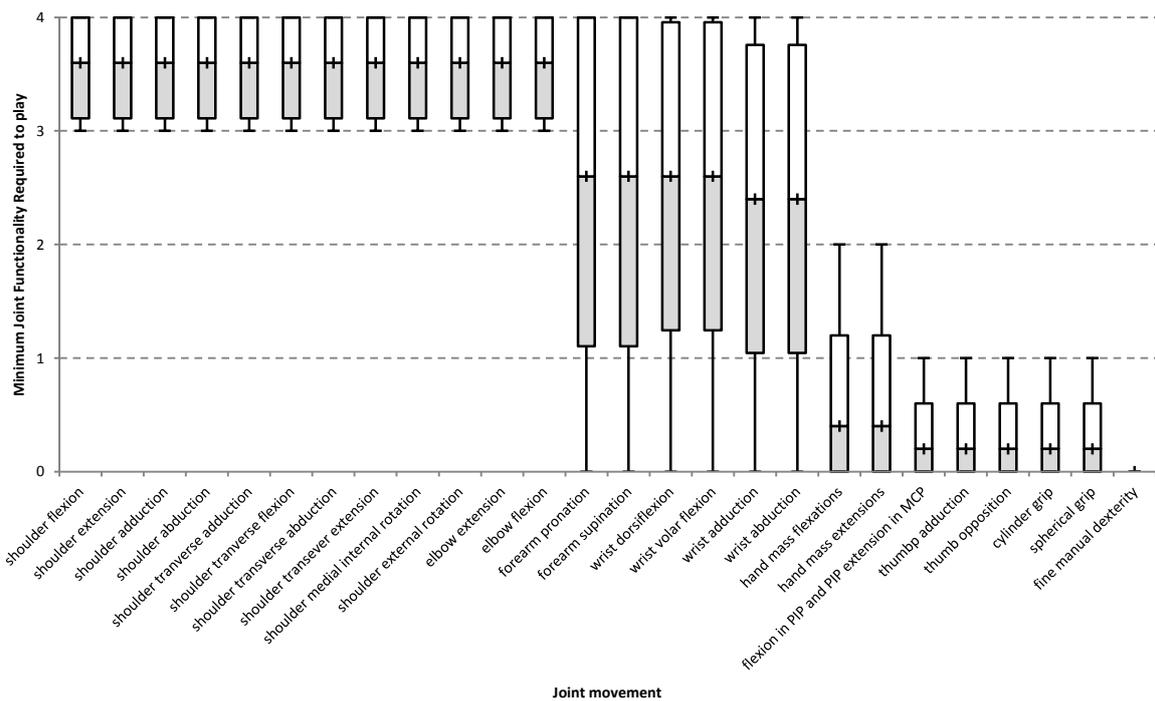
To visualise the results they have been graphed to show the mean score, standard deviation and range of the answers given. Of the two games tested, bowling was found to be more suitable for a stroke survivor as it required less arm and shoulder functionality to play. As shown in figure 2 bowling required a moderate to high level of shoulder mobility to play, a moderate amount of elbow movement and very little wrist and hand movement. Comparatively table tennis as shown in figure 3 is far more intensive and requires a much higher level of motor functioning. This could be due in part to the time limitations of each activity. Bowling allows the player to take an indefinite amount of time to bowl each ball. Table tennis by contrast requires the player to make timed reactions to the computer opponent. Cross body movements were required to perform backhand shots, this probably explains the increase in the amount of high intensity shoulder movements required.

Both games required little to no hand and wrist movement. This fits with our understanding of how the skeletal tracking algorithm works as it is unable to track wrist rotations and hand pose. Therefore we would expect games not to require wrist and hand movement as they are unable to detect them. Therapists did however feel that the games encouraged a greater range of joint movements than the system required. As shown in figure 4, therapists found themselves using hand and wrist motions when playing. As the games mimic real world activities the players may feel the need to match the normal movements even if they are not required by the Kinect games. In bowling therapists found themselves making hand grip and release movements when picking up and throwing the ball.



0. No motion required. 1. Reduced range of motion. 2. Partial range of motion. 3. Partial range of motion against gravity. 4. Full range of motion against gravity.

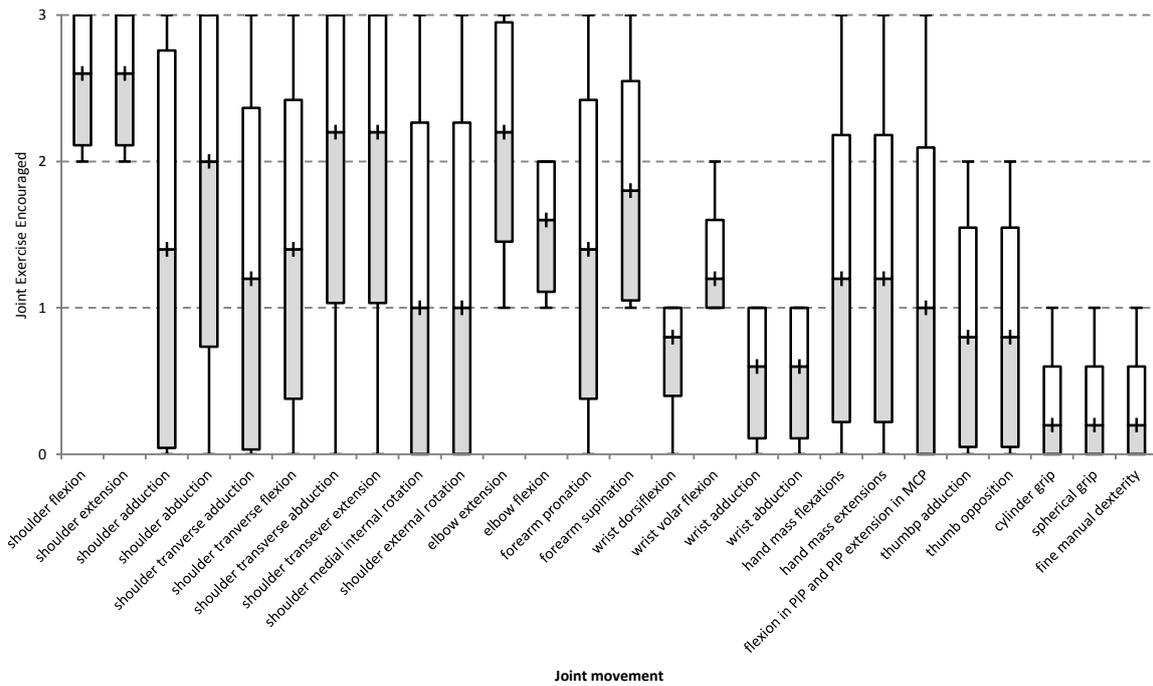
**Figure 2.** Minimum joint functionality required to play bowling.



0. No motion required. 1. Reduced range of motion. 2. Partial range of motion. 3. Partial range of motion against gravity. 4. Full range of motion against gravity.

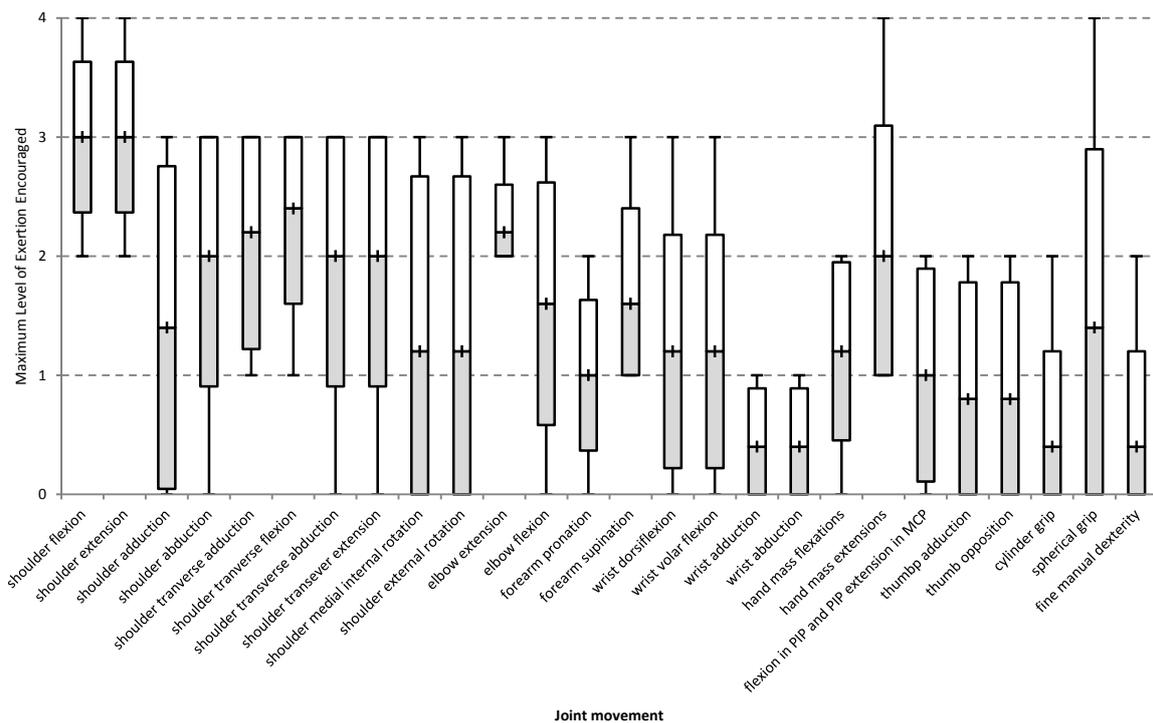
**Figure 3.** Minimum joint functionality required to play table tennis.

By encouraging joint movements in this way the games could provide a wider rehabilitation benefit to more joints in the arm than are traceable by the Kinect camera. However as the joints are not tracked there is no guarantee that the user is performing them. This may be useful in a supervised therapy session where the therapist can observe the patient's movements. However in an independent usage situation there would be no record of the patient's hand movements and would be of reduced usefulness for telerehabilitation.



0. Not encouraged. 1. Encouraged but not required. 2. Implicit to fulfilling required task. 3. Explicit to fulfilling required task.

**Figure 4.** Joint exercise encouraged for bowling.



0. No exertion. 1. Low. 2. Medium. 3. High. 4. Dangerous

**Figure 5.** Maximum level of exertion encouraged for bowling.

Therapists were also asked to rate how intensively they were using each joint during play as shown in figure 5. Most joint movements were found to be low to medium intensity. This is good as many stroke survivors will have a weakened upper limb and may fatigue quickly when performing intensive tasks. Shoulder flexion and extension movements were found to be very intensive. This is because the game requires the user to make a large

swinging movement at the shoulder. This is problematic for a stroke survivor as many will not have the required range of motion. This could present a barrier that they are unable to overcome and thus not be able to use the game.

### 3.1 Qualitative Findings

Therapists were asked to provide additional feedback about their experience. Common feedback included raising concerns about the balance risks while using the device. As the game does not work in a seated position, players must be standing. Many stroke survivors have reduced mobility, placing them at an increased risk of falling. Because of the motor impairments stroke falls can be extremely dangerous as often the victim is unable to break the fall using their upper limb. This makes the Kinect a potentially dangerous system to use for rehabilitation, especially when unsupervised. Several therapists also expressed the desire for seated play as many survivors are unable to stand unaided so could not use the system. When developing bespoke games, allowing them to be played in a seated position should be considered a high priority.

Concerns over the game's graphical interface were also raised. Kinect Sports is designed to mimic sporting television coverage. This includes fast camera cuts and pans; detailed environments including crowds and decorative lighting; and statistical overlays that appear periodically. Cognitive deficit can accompany motor deficit during stroke, and many stroke survivors will not be familiar with video games. Efforts should be made to provide a clearer graphical interface.

## 4. CONCLUSIONS

The off the shelf Kinect game Kinect Sports was evaluated to assess the feasibility of using it in its current form as a stroke rehabilitation aid. Two games from the title Kinect Sports were evaluated - bowling and table tennis. It was found that both titles were highly exertive on the shoulders and arms, while no wrist, hand or digit functionality was required at all. Although it was felt that wrist and hand movements were encouraged through the context of the exercises, as the Kinect does not track these motions it cannot be guaranteed that the user is performing them during play. Due to the high level of arm functionality required, it is likely that the games would only be useable by stroke survivors who have recovered a significant amount of motor functionality. Qualitative information was also gathered from therapists during the study, who believed the exercises combined with the requirement to stand while playing presented a real danger of fall and injury during play. It is concluded that off the shelf Kinect games are not suitable for most stroke survivors for unsupervised rehabilitation.

Adaptations that could be made to the evaluated games would be to allow play from a sitting position to reduce the risk of a fall and further injury. Kinect sports does not support seated play but a small number of Kinect COTS games do allow this e.g. Fruit Ninja Kinect and Kinectimals. Our results also showed that games require a high degree of joint functionality to play especially with regards to shoulder movements. This limits to potential audience to stroke survivors who have already regained a high degree of joint functionality. This is because the games are designed for able bodied users without accessibility in mind. By altering the game design to rely on less exerting movements would increase the number of users who are able to play. One instance of this is in Kinect Sports Bowling the player is required to hold their arm out to the side to pick up a ball. This is a difficult move and not possible for a large number of stroke survivors especially during rehabilitation. By providing alternative ways to perform these actions would allow people with less arm functionality to participate more.

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