EVALUATING THE HIP RANGE OF MOTION USING THE GONIOMETER, THE NINTENDO WIIMOTE AND VIDEO TRACKING METHODS

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Abstract

The range of motion (ROM) of the hip joint is an important clinical parameter used in diagnosing femoroacetabular impingement (FAI). Early detection of FAI helps people avoid the development of osteoarthritis. The goniometer is the most common method employed to measure joint angles. However, it has several limitations with respect to allowing clinicians to analyse the ROM at the gate, and tracking the hip joint during walking or in maximum squat. Motion capture devices used for analyzing the patient's gait and assessing the condition of joints and bones are accurate but require significant logistical and financial investment. The Nintendo Wiimote, used typically in games, has found its way to medical applications such as rehabilitation interventions and shows promise. This is the first study of its kind to evaluate the goniometer, a bespoke Wiimote system as well as a marker-based motion capture (MoCap) system to measure ROM. The aim of the article is to develop and assess a reliable, validated, easy to apply but scientifically sound method to measure ROM. This study used three methods to measure ROM. Namely, a high-spec marker-based MoCap system (Vicon), a markerless MoCap system (bespoke Wiimote system) and the conventional goniometer to examine the range of motion of 20 subject volunteers. This is the first of its kind to evaluate these three methods. The intraclass correlation coefficient (ICC) of the three methods is higher than 0.8 which shows that the reliability of all the methods is adequate. The validity of the marker-based MoCap system and the bespoke Wiimote is the same and furthermore, it is sufficiently robust to be used in clinical assessment. The marker-based MoCap system has slightly higher reliability and validity compared to the bespoke Wiimote system but the latter is easier to deploy, lower in cost, a more portable method and allows surgeons to have one free hand in order to avoid pelvic rotation and errors. The limitation of this study was the use of non FAI volunteers. It is concluded that the

Wiimote can be used instead of the goniometer in clinical settings. The Wiimote is easy to use, portable, reliable and accurate.

Keywords: Hip impingement, motion capture, FADIR test, Wiimote

Introduction

MoCap systems are used in various medical applications: to improve the performance of athletes, for analysis of the gait of patients and to assess the condition of joints and bones. In general, video tracking has been increasingly used by medical systems to aid the diagnosis and to speed up the operator's task (Charbonnier, Assassi, Volino, & Thalmann, 2009). However, there is a number of logistical issues related to the use of such a sophisticated system. The dedicated space and a controlled environment with special characteristics (a MoCap studio) necessitate financial investment. Furthermore, the requirement that the sensors used in such systems are in direct sight of the capturing cameras, restricts the application areas, particularly in scenarios where there needs to be more than one person and interactions between all those involved. In patient-surgeon scenarios the second person can obstruct the area of interest and thus the MoCap functionality is limited.

The Nintendo Wii Remote, also known colloquially as the Wiimote, has motion sensing capability, which allows the user to interact with and manipulate items on a screen via gesture recognition and pointing. This is achieved through the use of an accelerometer, a gyroscope and optical sensor technology. The Wiimote is designed for gaming platforms and therefore if it is to be used in health related application it has to undergo bespoke adaptions. Another of its beneficial features is its expandability through the use of attachments. An attachment that can be bundled with the Wii console is the nunchuk, which complements the Wii Remote by providing functions similar to those of gamepad controllers (Titterton & Weston, 2014). Three-dimensional measurement tools based on electromagnetic tracking have recently been used to measure precisely shoulder and spine ROM, as well as patellofemoral and hip joint (Kubiak-Langer, Tannast, Murphy , & Langlotz, 2007) kinematics. Electromagnetic tracking systems (ETS) enable the direct measurement of a three-dimensional position and the orientation of multiple sensors to a stationary source (transmitter) (Nussbaumer , et al., 2010).

The aim of this study is to propose the use of a bespoke Wiimote platform to measure ROM and evaluate it against the conventional method, the goniometer, and a sophisticated and base-line accurate system, the Vicon MoCap system. This paper is organized and structured as follows. Following the presentation of related work, the methodology and study design are presented Next, the findings are reviewed and then discussed in depth.

Finally, the conclusions of this study are presented along with proposals for future research in this area.

Using the FADIR test (**F**lexion, **AD**duction, and **I**nternal **R**otation) to detect impingement is one of the main means of physical impingement detection. Surgeons use the FADIR test to diagnose whether someone has impingement (Kubiak-Langer, Tannast, Murphy , & Langlotz, 2007), (Kuhlman & Domb, 2009), (Clohisy, et al., 2009). Patients who suffer from FAI usually have antero-lateral pain which appears slowly and progressively and they tend to cup their antero-lateral hips with fingers and thumb forming a “c” shape (Kuhlman & Domb, 2009) when indicating this pain. Moreover, they have sharp pain while turning towards the problematic side and the situation can deteriorate when sitting for a long time, leaning or going into and outside from the carse. The clinical examination of the hip starts with an overview of the problem, palpation and motion range assessment. The FADIR testing has been taken to be the most reliable examination to detect FAI (Kuhlman & Domb, 2009). This test has been used to examine FAI in clinical settings and with computer-aided programs.

Related Work

Nussbamer et al. (Nussbaumer , et al., 2010) suggest that goniometer-based assessments considerably overestimate hip joint ROM by measuring intersegmental angles (e.g. thigh flexion on the trunk for hip flexion) rather than true hip ROM. It is likely that uncontrolled pelvic rotation and tilt, due to difficulties in placing the goniometer correctly and in performing the anatomically correct ROM, contribute to the overrating of the arc of these motions.

The dislocation technique of surgical hips has been used for identifying the FAI mechanism (Ganz, Leunig, Leunig-Ganz, & Harris, 2008). In most cases, patients complain about anterior groin pain, which is then worsened by flexion on the hip (Kuhlman & Domb, 2009). Patients also complain that this pain is associated with long term sitting and getting into and out of the car. FAI has been considered as main reason for hip pain, reduced levels of motion range in athletes and reduced levels of performance (Nussbaumer , et al., 2010). The mean time from the occurrence of symptoms at the beginning of FAI to final diagnosis is 3.1 years (Clohisy, et al., 2009) with delay and inaccurate diagnosis being the two main problems (Clohisy, et al., 2009). Early and accurate diagnosis avoids OA and damaging soft tissue (Clohisy, et al., 2009). The hip with FAI symptoms has an average 97 º flexion and 9º internal rotation in flexion (Leardini, Chiari, Della Croce, & Cappozz, 2005) . These values are lower than the 110 º -120 º for flexion and 30 º -40 º degrees for internal rotation in flexion reported in normal subjects (Clohisy, et al., 2009).

The hip joint ROM is a basic clinical parameter for diagnosing hip diseases, such as OA (Arokoski, Haara, Helminen, & Arokoski, 2004) (Holm, et al., 2000) or FAI (Leunig, Beaule, & Ganz, 2009) (Tannast, et al., 2007), and for monitoring the process of treatments (Bierma-Zeinstra, et al., 1998). Hip joint ROM is widely assessed using low-technology tools such as manual goniometers or inclinometers. The advantages of goniometry are its simplicity in assessing ROM, the direct measurement of joint angles without any data reduction process and the low cost of the instrument. The two-arm goniometer is still the most commonly used, economical and portable device for the evaluation of ROM (Lea & Gerhardt, 1995). However, there are some disadvantages with goniometry. The starting position, the centre of rotation, the long axis of the limb and the true vertical and horizontal positions can only be visually estimated; moreover, conventional goniometers must be held with two hands, leaving neither hand free for stabilization of the body or the proximal part of the joint (Lea & Gerhardt, 1995). There are also difficulties in monitoring joints that are surrounded by large amounts of soft tissue, such as the hip (Allard , Stokes, & Blanchi, 1995). In addition, manual goniometers assess joint flexibility only in two dimensions. However, as most hip ROM measurements in clinical practice are practically in-plane movements, this limitation is minor. It has been concluded that goniometric measurements of passive hip motion provide greater ROM data than the criterion instrument ***(ETS)*** (Nussbaumer , et al., 2010).

In other research studies (Nussbaumer , et al., 2010), (Kennedy, Lamontagne, & Beaule, 2009) MoCap technology was used to measure the ROM during squatting and walking for persons with normal hips and patients diagnosed with FAI. Patients with FAI had no differences in hip motion during squatting but had decreased sagittal pelvic range of motion compared to the control group. Many common daily activities, such as prolonged sitting, squatting, stair climbing, and athletic activities requiring a large ROM, produce hip pain in people with FAI (Kennedy, Lamontagne, & Beaule, 2009). These same studies show gate analysis for the hip joint with impingement during walking and maximum squat (Nussbaumer , et al., 2010), (Kennedy, Lamontagne, & Beaule, 2009). They have measured the range of motion for the hip with impingement during walking and squat. The results have shown that the range of motion decreases for cases with hip impingement compared to a normal hip. Nonetheless, there are some limitations inherent to joint kinematics studies resulting from generic calculations, marker misplacements (Lamontagne & Kennedy, 2009), joint centre determination, and skin or clothing artefacts (Della Croce, Leardini, Chiari, & Cappozz, 2005) (Leardini, Chiari, Della Croce, & Cappozz, 2005) (Reinschmidt, Van Den Bogert, Nigg, Lundberg, & Murphy, 1997).

In this study, the ROM of volunteers with normal hips is measured using a bespoke portable Wiimote system, a high-spec video tracking system and a mechanical goniometer. The objective of the study is to compare and validate the results of all three methods. The study aims to evaluate the flexion, adduction and internal rotation of a FAI hip at the impingement point using the aforementioned methods. Furthermore, we investigate whether the Wiimote is sufficiently reliable and valid to replace the goniometer in clinical applications and could serve as a more accurate, user friendly and low-cost tool.

Methods

A total of 20 female healthy volunteers were evaluated and assessed under the FADIR test. In this study, the aim was to recruit volunteers of the same gender, similar age and BMI to keep all parameters coherent so as to measure the validity and reliability of the three different methods. The demographic information of volunteers is shown in Table 1. All volunteers provided written informed consent and completed an information sheet prior to data collection. Ethical approval for the study was gained from the Ethics Committee of Brunel University.

Table 1: Volunteers used in the experimental examination for this study

Subject volunteers	*Gender*	*Age*	*BMI(Kg/m^2)*
Volunteer	Female	28±2	18.37±3.15

Study Design

Subjects were tested twice, one week apart, in an environment of constant temperature and at the same time of day. This was necessary for the test-retest reliability of the Wiimote, the MoCap system and the goniometer for hip ROM assessment. Concurrent validity tests were established for each instrument and the goniometer was chosen as the criterion instrument. The data pertaining to all instruments were validated by the goniometer. The goniometer is accepted by the majority of scholarly work (Nussbaumer , et al., 2010), (Clohisy, et al., 2009) as the accepted clinical instrument for measuring ROM. Three trials were tested per each movement. A single investigator with experience in muscular examination who was blind to the volunteers' characteristics led all the ROM movements. Twenty volunteers were tested each day with a 30 minutes break between the tests. Each volunteers was tested three motions (flexion, adduction and internal rotation) and then there was 30 min break before physiotherapist started the next volunteer.

Measurement using a video tracking technique

A motion capture laboratory with seven Vicon Blade 1.7.0 cameras was used in the experimental examination. The Blade software calibration was deployed to control the system. After placing the markers on the subject volunteer, the system was calibrated so as to correlate with the real marker position in the 3D space of the software. The 3D space, origin and floor plane were calibrated in the software before starting to receive actual data from the subjects. An accurate calibration process is critical for generating precise motion capture data and is therefore a key initial step in the use of such systems and spending approximately 15 to 20 minutes on this task guaranteed the production of accurate information from the markers. The discussion below detailing the calibration process provides insights regarding the technical challenges related to the use of such systems.

By turning on the Vicon switch, all cameras connected to the computer and the Blade software became available for operation (see Figure 1). Before starting the operation, it was important to perform a check on the camera hardware settings and to select the recommended settings for the motion capture test. All the cameras required refiguring to these settings before use.

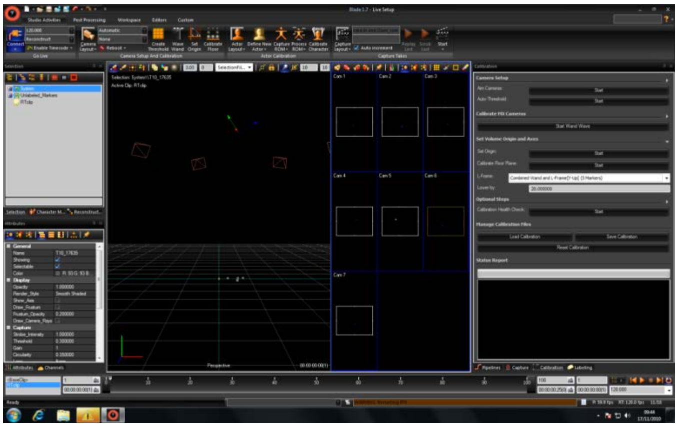


Fig. 1. Illustration of the Blade software start-up windows

3D space calibration

The 3D space calibration was performed using a T-shaped calibration wand to which five markers were attached. This is a standard calibration method. The wand was placed in the middle of the motion capture area, and then the calibration was started. In the next step the wand was waved slowly around the room to define the general 3D space area. It was then waved close to the floor area around the room to define the minimum 3D space area. Finally, the wand was waved up and down to define the maximum 3D space area. After this, the wand was placed in the middle of the space, and the calibration process was stopped.

Calibration of the origin

To define the origin, the wand was placed in the middle of the room. The wand’s handle was pointed in the negative direction to define the directions of the X and Y axes. The software was then zoomed to locate all the cameras in the 3D space. The “Calibrate Origin” function was then performed and all cameras were adjusted to above the floor plane.

Floor plane calibration

To calibrate the floor plane, either wand or markers can be used but placing markers around the floor gives a better representation of the floor since it is not as perfectly flat as in the software domain. Five markers were placed on the floor space within the 3D space area. Then the floor plan calibration was carried out. After finishing the calibration process, an example was tested to make sure the device was working perfectly.

Motion capture of the hip

According to the anatomy palpation and surface markings, the places for the markers on the motion capture skin suit were selected (Arokoski, Haara, Helminen, & Arokoski, 2004) (Holm, et al., 2000). Six markers, as shown in Figure 2, were attached to the lower limb body to capture the motion of the hip. The location of each marker was recorded against time according to its coordinates in the 3D space, which had already been defined in the software.

The rotation of the hip was measured based on the flexion, adduction to the maximum range and internal rotation up to 90 degrees of flexion. Figure 3 shows the first step in measuring the flexion of the hip. The position of the reference markers before and after flexion was measured. The flexion angle was calculated based on Equation (1).

$\text{Cos } \alpha = (|ba|2+ \; |ba`|2+ \; |aa`|2)/2 \; (|ba|)(|ba`|)$ (1)

Fig. 2. Six markers were attached to the lower limb body to capture the motion of the hip

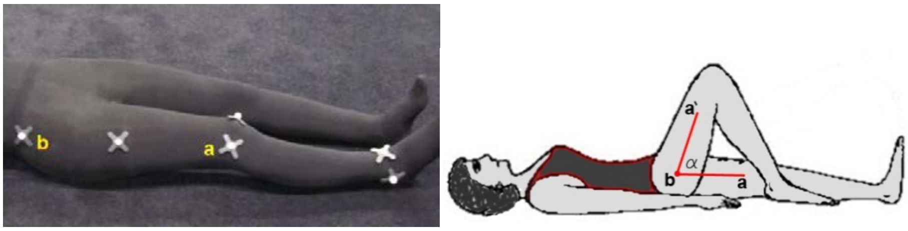


Fig. 3. Marker b was the refrence marker and the position of marker a, before and after full flexion, was measured to find the flexion angle

Fig. 4. To measure the adduction, the leg was positioned toward the centre of the body

The flexion angle can be calculated by knowing the coordinates of the markers at points b, a, a` and the distances |ba|, |ba`| and |aa`|. To measure the adduction, as illustrated in Figure 4, the leg of the subject volunteer was positioned toward the centre of the body. The markers‘ positions before and after the movement were recorded. The adduction angle was calculated from Equation (1).

The same procedure as above for adduction was applied for the internal rotation in 90° flexion, as shown in Figure 5. The leg was positioned toward the center of the body while it was at the hip and knee 90° flexion. The positions of the markers at the start and stop points of the internal rotaton were recorded and the angle calculated using Equation (1).

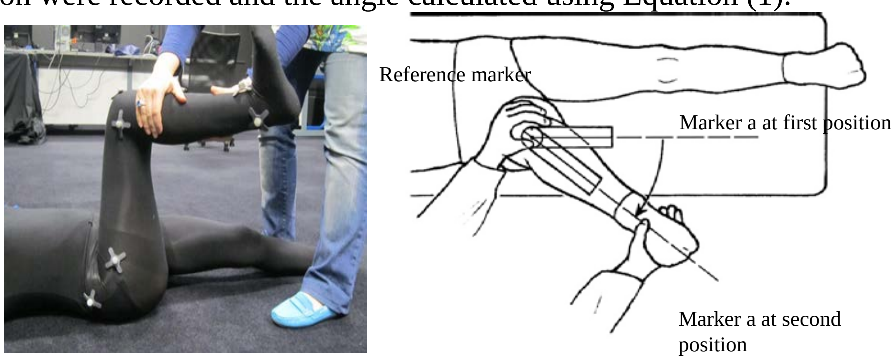


Fig 5. To measure the internal rotation the leg was forced outward from the centre of the body

Measurement using the bespoke Wiimote system

The Wiimote was used to measure flexion, adduction in 90° flexion and internal rotation in 90° flexion in 20 healthy volunteers. "*The motion capture system employed for the purpose of this research comprised an off-the-shelf gaming sensor, i.e. the Ninteno Wiimote, and a bespoke communication interface between the Wiimotes (up to two) and local computers connected by Bluetooth and remote via the Internet*" (Tsekleves, et al., 2014).

"*The motion data received by the terminals undergo a process of smoothing and multiplexing by using a data fusion algorithm to achieve higher accuracy and precision. The end results are then mapped into quaternion forms that translate the orientation of a constructed 3D body model and are free from gimbal-lock. The angular rate measurements captured by the gyroscope sensor can be used to distinguish true linear motion from the accelerometer readings. The gyroscope is not free from noise, but since the measured rotation is less sensitive to linear mechanical movements and without amplifying hand jitter, both of which are experienced with accelerometers, it allows for the capture of more complex orientation with a relatively better estimate than we would obtain by using accelerometers alone. A sensible approach for maximising efficiency is to average or concatenate the data that come from the accelerometer and gyroscope by using a data fusion algorithm. Simultaneously, we were able to employ a smoothing algorithm to remove any excessive noise from the signals while still retaining the useful information. Filtering out and removing as much random noise as possible from the sensors' outputed raw information whilst retaining quality data is of fundamental importance*" (Tsekleves, et al., 2012), (Warland , et al., 2012), (Tsekleves , et al., 2014).

"*The Wiimote sensors are very responsive but cannot respond to the linear movement which accelerometers specialise in capturing. However, as described in the above section, when a gyroscope and an accelerometer are combined, the pairing of sensors facilitates a highly accurate one-to-one representation of the control device in the 3D space*" (Tsekleves, et al., 2012). *The quaternion data are forwarded locally or online and thus manipulate a virtual 3D object on the local computer or provide biofeedback to the clinician (remote terminal). The aforementioned feature enables the remote monitoring of the whole procedure* (Tsekleves, et al., 2012), (Ojeda & Borenstein, 2002).

Figure 6 shows a schematic procedure of the Wii-remote control used to obtain the motion data. The obtained data are quaternion orientation. To change data from quaternion values to Euler angles, Equation 2 was used. Figure 7 shows the Euler angles.

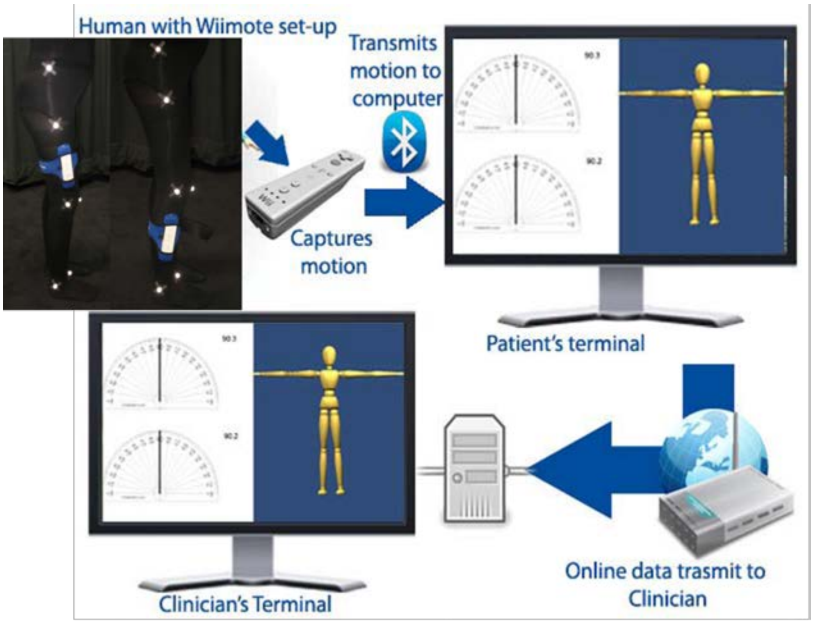
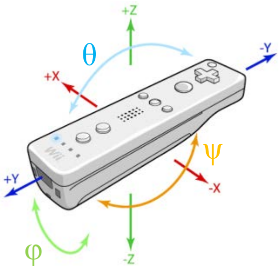


Fig 6. Schematic procedure of the Wii-remote control when capturing motion data



ψ =Atan2 $(2q_2q_3\text{-}2q_1q_4,\ 2q_1^{\,2}\text{+}2q_2^{\,2}\text{-}1)$
θ =-sin-1$(2q_2q4\text{+}2q_1q_3)$
(2)
φ= Atan2 $(2q_3q_4\text{-}2q_1q_2,\ 2q_1^{\,2}\text{+}2q_4^{\,2}\text{-}1)$
(Philippon & Schenker, 2006)

Fig 7. Euler coordinates in the Wii remote controller

Flexion

The subject volunteers were asked to bend their knee and bend their leg and bring it as close to their chest as was comfortable (fully flexed). The subject was then asked to lie supine in the anatomical position and in such a way that the fulcrum was aligned with the greater trochanter of the femur. The Wiimote controller was installed on the hip of the volunteers. When the volunteers were in the supine position with the hip relaxed, the angle was chosen as the reference and it was in 0 º (Figure 3).

Adduction

The subject volunteers were asked to move their leg inward, toward their opposite leg. The subject was supine in the anatomical position. The leg was measured when in full adduction (Figure 4).

Medial (internal) rotation

The hip was flexed 90 º (reference point when internal rotation is 0) then the hip was internally rotated (Figure 5).

Measurement using the goniometer

The hip range of motion including flexion, adduction and internal rotation in 90° of flexion was measured by applying an adjustable goniometer to the subject volunteers. The data for the above motions were recorded for each of the volunteers and used for comparison with the motion capture method data.

Flexion

The subject volunteers were asked to bend their knee and bend their leg and bring it as close to their chest as was comfortable. Each subject was then asked to lie supine in the anatomical position and in such a way that the fulcrum was aligned with the greater trochanter of the femur. The measurement then took place by locating the stationary arm of the goniometer along the lateral midline of the abdomen, using the pelvis for reference and the moving arm of the goniometer was placed along the lateral midline of the femur.

Adduction

The subject volunteers were asked to move their leg inward toward their opposite leg. The subject was supine in the anatomical position. The leg was measured when it was in full adduction. The fulcrum was placed in line with the anterior superior iliac spine and the moving arm of the goniometer was aligned with the midline of the patella.

Medial (internal) rotation

The subject brought their leg out to the side and then was asked to sit on the edge of the table, with their knees against the table, and their legs dangling down. The fulcrum was aligned with the patella and both arms of the goniometer aligned with the midline of the tibia. The stationary arm of the goniometer was then allowed to hang freely but perpendicular to the floor.

Statistical Analysis

Normality and homogeneity of data variance were tested. The data was then tried with a t-test. The reliability was assessed by using infraclass correlation (ICC) (2, 1). As a general rule, an ICC value over 0.75 is considered good and a corrected alpha level of $p \leq 0.01$ was accepted. Absolute reliability was analysed by using the coefficient of variation (CV) and the standard errors of measurement (SEM). The mean values and standard deviation were evaluated for each instrument and for each movement. The reliability of data was tested for two different times and the results for each volunteer compared and the ICC as well as SEM calculated. Flexion, adduction and internal rotation of each volunteer was tested in time t_1 using the Wiimote, motion capture and goniometer at the same time and again for time t_2. The results of t_1 and t_2 were compared separately for flexion by motion capture in each volunteer. Flexion, adduction and internal rotation of each volunteer was tested in time t_2 by Wiimote, motion capture and goniometer at the same time. The results of t_1 and t_2 was compared separately for flexion by Wiimote in a same volunteer. Flexion, adduction and internal rotation of each volunteer was tested in time t_2 by Wiimote, motion capture and goniometer at the same time. The results of t_1 and t_2 was compared separately for flexion by goniometer for each volunteer. Same comparison were applied for adduction and internal rotation.

The concurrent validity of the data was measured to determine the validity of the measuring techniques by comparing them with the established system; the goniometer. The concurrent validity between each measurement technique and the goniometer were analysed using the infraclass correlation coefficient (ICC) (2,1) with 95% confidence intervals. The validity of the Wiimote and the goniometer was compared with that for the motion capture. Flexion of each volunteer was measured by motion capture, Wiimote and goniometer at the same time. The results of the Wiimote and goniometer were compared with those from the motion capture (reference method).

Results

In this study, the ROM of twenty volunteers including flexion, adduction and internal rotation in 90°of flexion was measured using three methods, namely the video tracking (MoCap) technique, the bespoke Wiimote system and the goniometer instrument. The ROM of each volunteer was measured at least three times and the average result for each person used for comparison in the study.

Figures 8, 9 and 10 indicate the diagram of angles (flexion, adduction and internal rotation) in terms of time for the MoCap and Wiimote.

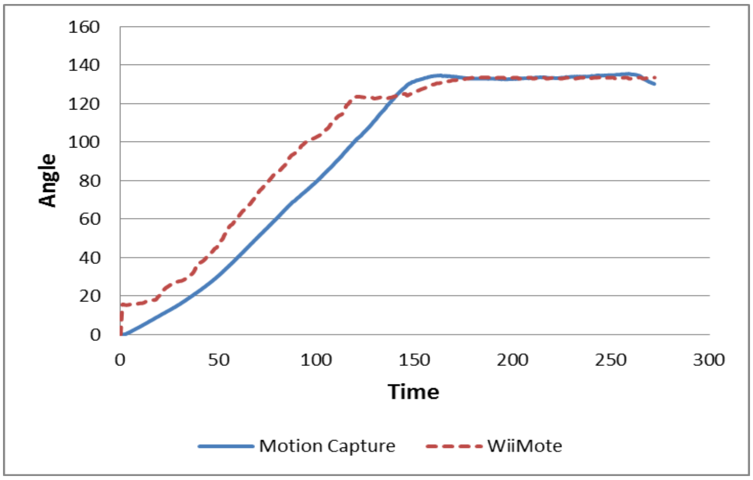


Figure 8: Example of the flexion angle in terms of time for the MoCap and Wiimote

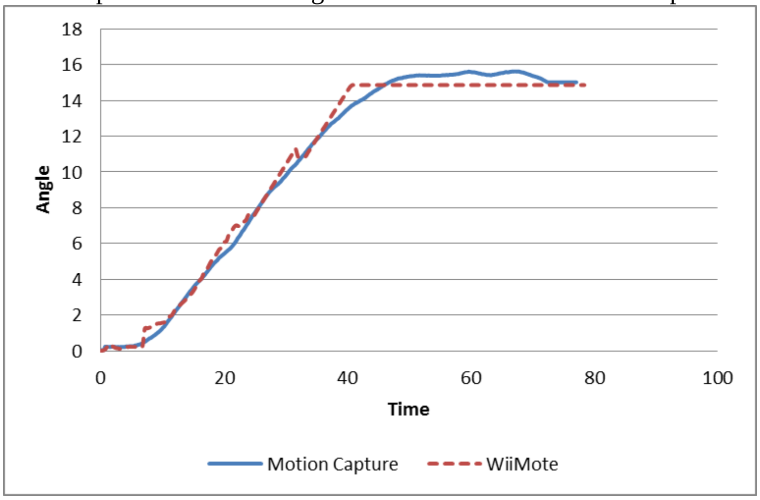


Figure 9: Example of the adduction angle in terms of time for the MoCap and Wiimote

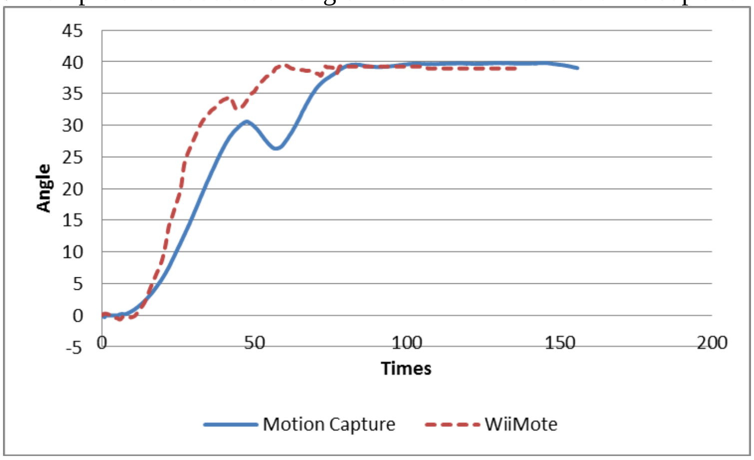


Figure 10: Example of the internal rotation angle in terms of time for the MoCap and Wiimote

Table 2 shows the reliability of the different measurement techniques. The ICC value, for all of the techniques examined, is higher than 0.7 which is very satisfactory regarding the validity of a new measurement method. In comparative terms, the Wiimote data shows good reliability. Moreover, this device is easy to use, it reduces human error and also allows surgeons to have both hands free in order to measure the ROM of patients. This is a limitation of sophisticated MoCap systems, such as the Vicon, where due to marker obstruction, it is highly likely that surgeons would not be able to interact with their patient during the measurement process.

A higher ICC means higher reliability. Nussbamer et al. (Nussbaumer , et al., 2010) measured ICC for ETS as between 0.8 and 0.94. However, our study showed a higher ICC, which means there is higher reliability for the Wiimote (Lower CV% means higher reliability). The same study by Nussbamer et al. (Nussbaumer , et al., 2010) also measured CV% for ETS as between 2.7 and 10. However, our study shows higher CV% (between 1 and 4) which means there is higher reliability for the Wiimote.

Table 2: Reliability test for all of the measurement techniques

	Flexion			**Adduction**			**Internal Rotation**		
	ICC	**CV%**	**SEM**	**ICC**	**CV%**	**SEM**	**ICC**	**CV%**	**SEM**
Goniometer	0.90	0.13	2.6	0.91	0.13	1.00	0.92	0.18	1.0
Wiimote	0.95	0.12	2.5	0.90	0.12	0.87	0.92	0.20	1.1
Motion Capture	0.97	0.14	2.7	0.95	0.12	0.95	0.92	0.15	0.92

Nussbamer et al. (Nussbaumer , et al., 2010) studied the validity and reliability of an ETS device and goniometer. Our findings show better reliability and validity ($p \leq 0.01$) for the Wiimote device compared to this aforementioned study for using the ETS device (Nussbaumer , et al., 2010). Additionally, our results show that the Wiimote can replace the goniometer in clinical applications to measure the ROM. Its higher ICC and lower SEM make the Wiimote appropriate for clinical applications. Table 3 presents the parameters of validity for the Wiimote and the goniometer. The ICC of both these is similar.

Table 3: Validity test for all of the measurement techniques (Motion Capture is used as the reference method)

	Flexion		**Adduction**		**Internal Rotation**	
	ICC	**LOA**	**ICC**	**LOA**	**ICC**	**LOA**
Wiimote	0.9	3.8	0.88	1.4	0.88	1.4
Goniometer	0.9	4.0	0.82	1.4	0.88	1.3

The study of Nussbamer et al. (Nussbaumer , et al., 2010) indicates that the goniometer overestimates the ROM of the hip joint and it records the intersegmental angle rather than the true hip ROM. Nevertheless, the goniometer can be used with confidence for longitudinal assessment in clinical practice. The level of agreement (LOA) is high for internal rotation.

Table 4 shows the previous results of measuring the ROM of the hip with the ETS and goniometer. Our findings indicate better outcomes for the Wiimote.

Table 4: Results of previous studies of the ICC, CV, SEM of the ETS and the goniometer (Nussbaumer , et al., 2010)

	ICC	CV	SEM
ETS	Above 0.9	2.7-10.2	1.6-3
Goniometer	2.4-3.9	3.1-7.7	6.6-11.2

Figures 11, 12 and 13 indicate distributions of data in terms of the reference method (MoCap) for the impingement angle (flexion, adduction in 90° flexion and internal rotation in 90° flexion). The data are valid as they are similar to the reference method. These figures further confirm that the Wiimote is sufficiently valid when measuring ROM.

Vertical axis in the Figures 11,12 and 13 stands for results of motion capture as a reference method. The line in the Figures 11,12 and 13 indicates linear line of x=y which means that every value in the x axis (motion capture) should have the same value in y axis (which are wiimote and goniometer). Figures 11,12 and 13 show the distribution of data along x=y axis. The best valid data should be along the line x=y and if the data are far from the line shows lower validity. The closest distribution of the points t the line shows the better validity of the device.

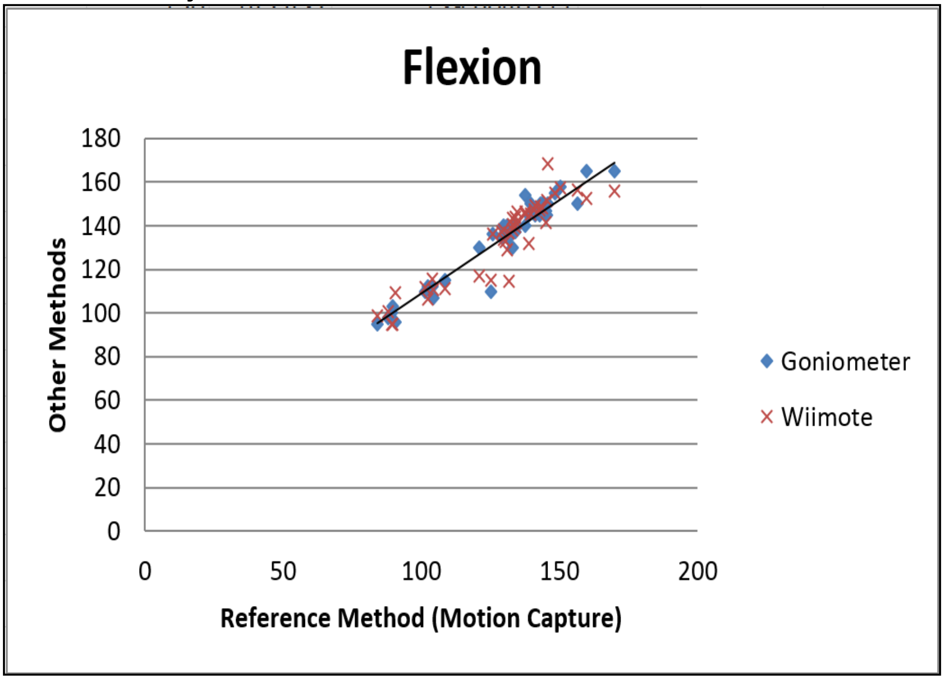


Figure 11 Correlation plot for flexion (motion capture was used as the refrence to compare the validity of the Wiimote and the goniometer)

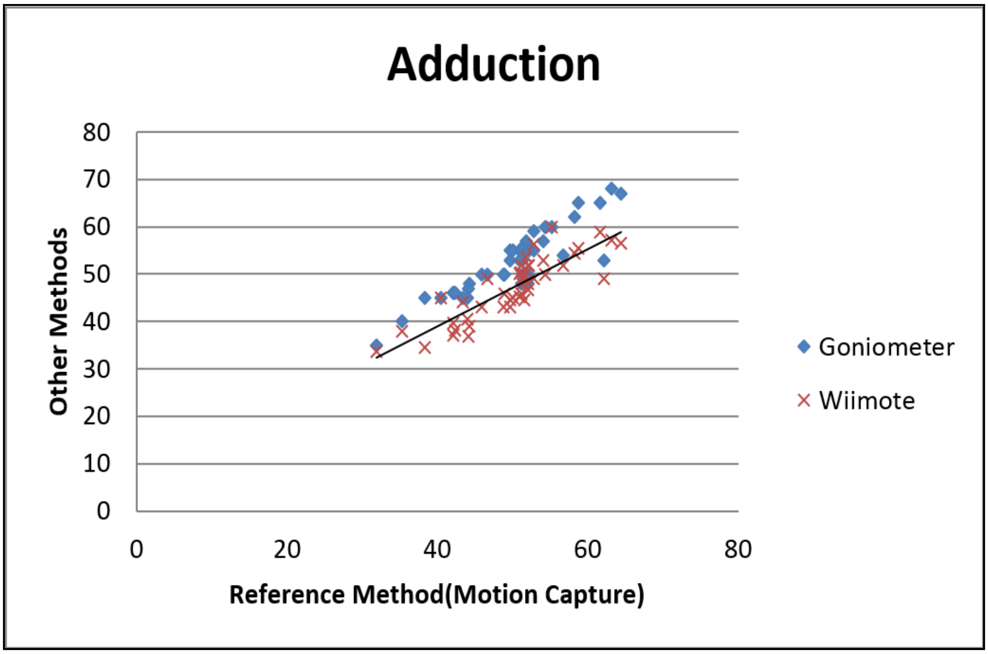


Fig 12: Correlation plot for adduction (Vicon MoCap was used as the reference to compare the validity of the Wiimote and the goniometer)

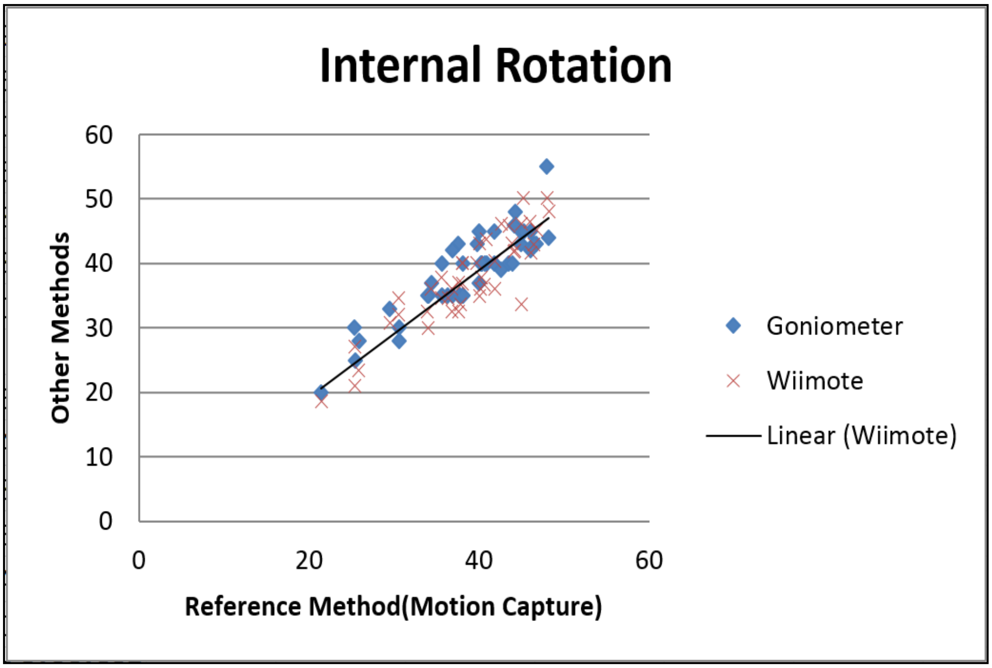


Fig 13: Correlation plot for internal rotation (Vicon MoCap was used as the reference to compare the validity of the Wiimote and the goniometer

Discussion

The results of this study indicate that the Wiimote can be used in medical applications instead of the goniometer because it has high reliability, validity and is convenient to use. It could be used in other medical fields, such as physical therapies, to measure the ROM.

The hip ROM measured by goniometer and Wiimote give results that are more valid than the results given previously (Nussbaumer , et al., 2010) when ETS were used. The LOA is about ±8° less than shown previous research for flexion and about ±6° less than the previous research results for adduction and internal rotation. Less LOA shows a higher level of validity and our results for the Wiimote have higher validity in terms of LOA than those reported previously for ETS (Nussbaumer , et al., 2010). Moreover, the ICC value for the Wiimote and the goniometer (0.92 to 0.97) are higher than previously reported (0.4) which indicates that there is higher reliability.

The SEM and CV% values obtained in our findings are less than previously reported (Nussbaumer , et al., 2010) which indicates higher reliability. Also the LOA degree for all of the hip motion is significantly less than those reported for ETS in Nussbaumer et al‘s article (Nussbaumer , et al., 2010). Previous work reported the CV % of 23% and 3.1- 7.7 % (Nussbaumer , et al., 2010).

This study was designed using normal subjects to assess the validity and reliability of measuring ROM in medical applications, specifically for hip impingement. However, more useful results could be obtained by using subjects diagnosed with hip impingement, similar to Nussbamer et al. (Nussbaumer , et al., 2010) who recruited patients. Another limitation of this study is the use of multiple Wiimotes, instead of one, for multiple joints. One should be placed in the middle of femur and the other one should be placed in the middle of tibia. In the future it could prove beneficial to compare these results with fluoroscopy outcomes to examine in more detail the results obtained in our study.

Conclusions

The Nintendo Wiimote is a portable device which can be easily integrated into a bespoke motion capture system. Its potential applications include clinical use for ROM measurements. The device is easy to use and furthermore enables surgeons to have one of their hands free when assessing the ROM of patients. We have investigated the validity and reliability of the bespoke Wiimote system and compared it with the Vicon motion capture system, of established sub-millimeter accuracy, and a conventional goniometer. The study results indicate that the Wiimote has high reliability and validity compared to the high-spec Vicon Mocap system. Since the use of sophisticated and expensive motion capture equipment such the Vicon system is not practical in clinical environments, a proposed alternative, the bespoke Wiimote system has been investigated and shown to be appropriate. The Wiimote offers a portable, easy-to-use, low-cost device suitable for measuring ROM and it helps to eliminate errors in measuring introduced when the goniometer is employed. The use of such an alternative is recommended as a replacement for conventional instruments in order to avoid human error. Future work will include further investigation and comparison of our results by using fluoroscopy for the measurement of joint ROM.

References:

Allard , P., Stokes, I., & Blanchi, J. (1995). *Three-dimensional analysis of human movement.* Champaign: Human Kinetics.

Arokoski, M. H., Haara, M., Helminen, H. J., & Arokoski, J. P. (2004). Physical function in men with and without hip osteoarthritis. *Arch Phys Med Rehabil* , 574-581.

Bierma-Zeinstra, S. M., Bohnen, A. M., Ramlal, R., Ridderikhoff, J., Verhaar, J. A., & Prins, A. (1998). Comparison between two devices for measuring hip joint motions. *Clin Rehabil*, 497-505.

Charbonnier, C., Assassi, L., Voli, P., & Magnenat-Thalmann, N. (2009). Motion study of hip joint in extreme postures. *Visual Computer*, 873-882.

Clohisy, J. C., Knaus, E. R., Hunt, D. M., Lesher, J. M., Harris-Hayes, M., & Prather, H. (2009). Clinical presentation of patients with symptomatic anterior hip impingement. *Clin Orthop Relat Res*, 638-644.

Della Croce, U., Leardini, A., Chiari, L., & Cappozz, A. (2005). Human movement analysis using stereophotogrammetry, Part 4: assessment of anatomical landmark misplacement and its effects on joint kinematics. *Gait Posture*, 226-237.

Ganz, R., Leunig, M., Leunig-Ganz, K., & Harris, W. (2008). The etiology of osteoarthritis of the hip: an integrated mechanical concept. *Clinical orthopaedics and related research*, 264-272.

Holm, I., Bolstad, B., Lutken, T., Ervik, A., Rokkum, M., & Steen, H. (2000). Reliability of goniometric measurements and visual estimates of hip ROM in patients with osteoarthrosis. *Physiother Res Int*, 241-248.

Kennedy, M. J., Lamontagne, M., & Beaule, P. E. (2009). M. J. Kennedy, M. Lamontagne, P. E. Beaule,Femoroacetabular impingement alters hip and pelvic biomechanics during gait walking biomechanics of FAI. *Gait & Posture*, 41-44.

Kubiak-Langer, M., Tannast, M., Murphy , S., & Langlotz, F. (2007). Range of Motion in Anterior Femoroacetabular Impingement. *Clinical orthopaedics and related research*, 117-124.

Kuhlman, G. S., & Domb, B. G. (2009). Hip impingement: identifying and treating a common cause of hip pain. *American Family Physician*, 1429-1434.

Kuhlman, G., & Domb, B. (2009). Hip impingement: identifying and treating a common cause of hip pain. *American Family Physician*, 1429-1434.

Lamontagne, M., & Kennedy, M. J. (2009). The effect of cam FAI on hip and pelvic motion during maximum squat. *Clin Orthop Relat Re*, 645-650.

Lea, R. D., & Gerhardt, J. J. (1995). Range-of-motion measurements. *J Bone Joint Surg Am*, 784-798.

Leardini, A., Chiari, L., Della Croce, U., & Cappozz, A. (2005). Human movement analysis using stereophotogrammetry. Part 3. Soft tissue artifact assessment and compensation . *Gait Posture*, 212-225.

Leunig, M., Beaule, P. E., & Ganz, R. (2009). The concept of femoroacetabular impingement: current status and future perspectives. *Clin Orthop Relat Res*, 616-622.

Nussbaumer , E., Leunig , M., Glatthorn, J., Stauffacher , S., Gerber, H., & StMaffiuletti , N. (2010). Validity and test-retest reliability of manual goniometers for measuring passive hip range of motion in femoroacetabular impingement patients,. *BMC Musculoskeletal Disorders*, 2-11Nussbaumer S1, Leunig M, Glatthorn JF,.

Ojeda, L., & Borenstein, J. (2002). Flexnav: fuzzy logic expert rule-based position estimation for mobile robots on rugged terrain. *International Conference on Robotics and Automation.* German: IEEE.

Philippon, J. M., & Schenker, B. L. (2006). J. M. Philippon, B. L. Schenker, “Arthroscopy for the treatment of femoroacetabular impingement in the athlete. *Clin Sports Me*, 299-308.

Reinschmidt, C., Van Den Bogert, A. J., Nigg, B. M., Lundberg, A., & Murphy, N. (1997). Effect of skin movement on the analysis of skeletal knee joint motion during running. *J Biomech*, 729-732.

Tannast, M., Kubiak-Langer, M., Langlotz, F., Puls, M., Murphy, S. B., & Siebenrock, K. A. (2007). Noninvasive three-dimensional assessment of femoroacetabular impingement. *J Orthop Res*, 122-131.

Tsekleves, E., Skordoulis, D., Paraskevopoulos, I., Kilbride, C., & Warland, A. (2012). Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus. 9th Intl Conf. Disability, Virtual Reality & Associated Technologies, (pp. 515-518). Laval, France.

Tsekleves, E., Paraskevopoulos, I. T., Kilbride, C., Warland, A. (2014). Development and preliminary evaluation of a low cost VR-based stroke rehabilitation platform that uses the Wii technology. *Disability and Rehabilitation: Assistive Technology Journal*.

Warland, A. Kilbride, C. Tsekleves, E. Skordoulis, D. Paraskevopoulos, I. (2012). ReWiiRe (Research in Wii Rehabilitation): User involvement in the development of a personalised rehabilitation system for arm re-education after stroke: *International Journal of Stroke*, 79-83.