A Review Evaluating the Validity of Motion-Based Gaming Platforms to Measure Clinical Outcomes in Clinical Research

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Abstract

OBJECTIVES:
Motion-based video game platforms provide the capability to track 3D body movements and may offer a versatile, easy to use and low-cost approach to measuring objective clinical outcomes. We reviewed published validation studies comparing clinical outcomes derived from video game platforms to gold-standard approaches.

METHODS:
We categorized studies in our review into three areas of application and summarized validation findings. We confined our review to studies using the Microsoft Kinect platform due to the volume of work in this area.

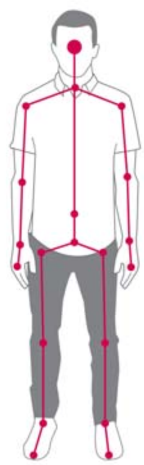
RESULTS:
Gait and balance: Five validation studies reported varied findings. One study in MS reported good correlation of most parameters with ClinROs; and a second study reported good validation of walk test parameters in Stroke patients. A treadmill test in healthy volunteers found Kinect under-estimated joint flexion and over-estimated extension; and a further study was able to detect gait disturbances in MS during a speed-walking test compared to healthy volunteers although correlation to clinician assessment was modest (r=0.447). Kinect use during a battery of balance and dexterity tests in PD accurately measured the timing (ICCs: 0.940-0.999) and gross spatial characteristics of clinically relevant movements, but spatial accuracy for smaller movements, such as toe tapping (ICC = 0.038), was poor.
Upper extremity movement: Eight studies reported good validity in measurement of shoulder range of motion (r's > 0.8, ICCs > 0.864).
Spirometry: One study reported strong correlation of spirometry parameters (r>0.866) estimated using multiple sensors to generate a 3D image of the chest.

CONCLUSIONS:
Motion-based video gaming platforms offer potential for low-cost assessment of movement and mobility in large-scale clinical trials without reliance on specialist centers. Studies report good validity in some application areas. The ability to provide the level of accuracy needed in more rapid and finer movements requires more validation work.

Introduction

A number of gaming systems enable motion-based gaming experiences and utilize a depth camera to track movements to enable players to engage with video game content. These same platforms can be leveraged to track movement in a range of healthcare and wellness applications. In particular, the Microsoft Kinect sensor, a component of the Xbox gaming system, has been particularly successful in enabling the development of health applications due to the ability of the Kinect to operate on a PC platform and the utility of its associated Software Development Kit (SDK) to facilitate the development of applications that track body movements.

In particular, there is a growing body of applications leveraging Microsoft Kinect in developing interactive solutions for rehabilitation including novel ways of engaging patients in regular exercise regimens and ensure that exercises are performed correctly for optimal outcomes. These applications use the skeletal tracking module within the Kinect SDK. This enables the 3D position of 26 body joints to be tracked over time without the need for the patient to wear sensors, special clothing or special markers.



This same capability can be used to record and measure aspects of movement during performance tasks completed by the patient, enabling the objective measurement and tracking of movement and mobility related outcomes measures.

In this review we explore the use of the Kinect platform to develop low-cost approaches to objectively measure aspects of movement. We consider published applications that measure aspects of gait and balance, upper extremity movement and chest wall motion. In each case, we explore the utility of the approach for clinical trials, and the precision and accuracy of estimates derived from the Kinect output.

Methods

We performed a literature search for studies utilising Microsoft Kinect to measure health outcomes. To be included, studies needed to report the validation of measures observed using Kinect with an alternative accepted approach. We collected additional descriptions of the performance tests applied, and aspects of the methodology employed that may influence the accuracy of outcomes measures obtained.

We categorise studies in our review into three application areas: those measuring aspects of gait and balance, those measuring joint range of motion and specifically upper extremity range of motion (although other studies not included in our review considered other joints), and chest wall motion analysis to derive measures of respiratory function.

Results

Gait and balance
We reviewed 5 validation studies using a variety of performance tests to measure aspects of gait and balance using Kinect in a variety of disease indications including Multiple Sclerosis [1,5], Stroke [3] and Parkinson's Disease [4].

Ref	Performance	Measure	Comparator	n	Validation evidence
[1]	Treadmill walking tests	Hip/knee flexion/extensio n Stride timing	VICON motion capture	28	Kinect underestimated flexion, overestimated extension. Stride timing often well correlated.
[2]	Short walk	Velocity, stride length, hip/knee ROM	PRO (MSWS) ClinRO (EDSS)	20	Able to distinguish MS form controls Reliability good except step width and hip ROM
[3]	6 m walk	Step length, foot swing velocity, mean and peak gait velocity, asymmetry	10mWT, TUG, Step test	30	Kinect parameters reliable: ICCs > 0.8 Feasible to instrument gait analysis
[4]	Standing, stepping, walk on spot, UPDSS	Various	VICON motion capture	19	Good for gross movements Poor for fine movement Good correlation with VICON (r > 0.8)
[5]	Short max speed walk	Speed; L/R, Up/Down and 3D deviation; speed deviation	25 foot walk test	44	Able to differentiate MS and controls Good concordance with 25-foot walk test

Studies aimed to measure a range of gait / balance parameters including hip/knee range of movement, walking velocity and stride length, swing velocity, and aspects of asymmetry in movement. For example, gait event times for ground contact and toe-off could be estimated based on the velocity of the ankle joint center, which in turn can enable estimation of step length and foot swing velocity. Operationally, the Kinect-based assessment system offered a marker-less approach which is simpler and cheaper to operate in comparison to other motion capture or pressure mat systems. Subjects conducted performance tests in normal clothes, not requiring shorts or bare feet.

In general, Kinect was able to measure some gross movements with reasonable accuracy, but was less capable of measuring finer or more rapid movements. For example, a study using a battery of functional performance tests in Parkinson's disease patients showed promise in the use of the Kinect depth camera in measuring some but not all clinical outcomes measures [4]. The tests included quiet standing, multidirectional reaching, stepping and walking on the spot, and a number of functional test from the UPDRS. In comparison to a Vicon 3D motion analysis system, Kinect was able to accurately measure the timing (ICCs: 0.940-0.999) and gross spatial characteristics of clinically relevant movements but not provide the same spatial accuracy for smaller movements, such as toe tapping (ICC = 0.038).

The sampling rate of the Kinect depth camera is 30 Hz, which may not be suitable for accurate measurement of rapid and fine movements. Some authors [3] used spline interpolation to re-estimate movement with 100 Hz sampling frequency. In addition, other authors [5] developed additional algorithms to improve the in-built error detection system (SDK Recognition Quality) which works to identify data artefacts affecting the ability to track the position of each joint. This custom error correction technique was able to significantly improve accuracy of joint tracking compared to the Kinect SDK.

Upper extremity movement
We reviewed 8 validation studies using Kinect to measure upper extremity movement in disease indications including Adhesive Capsulitis [6], Stroke [7] and Multiple Sclerosis [13].

Ref	Performance	Measure	Comparator	n	Validation evidence
[6]	Shoulder movement	Shoulder flexion, abduction, rotation	Goniometer	27	ICCs: 0.864-0.942
[7]	FMA / ARAT	Shoulder/elbow/ wrist flexion, abduction, rotation	Impulse motion cap. + clinician ass.	9	MC: $R^2 = 0.64$, $p < 0.001$ Clin. Ass: $R^2 = 0.86$, $p < 0.001$
[8]	Arm movement	Shoulder flexion, abduction, rotation, extension	Goniometer	10	r = 0.86 to 0.99
[9]	Arm movement	3D workable reaching space	Impulse motion capture	10	$R^2 = 0.79$
[10]	Pediatric Functional Assessment	Index finger and thumb, wrist, elbow, shoulder ROM	Clinician assessment	12	"Technically sound approach"
[11]	Movement task	Involuntary movements / dyskinesia	Clinician assessment	4	Cohen's kappa 0.85, $p < 0.05$
[12]	Fugl-Meyer, WMFT, ARAT	Shoulder, elbow and wrist position	Optitrack motion capture	10	"Kinect is sufficiently accurate and responsive"
[13]	Arm/hand movements	Machine learning identification	Differentiate MS from HV	104 1	"Automated MS assessment possible"

In general, performance tests included asking the patient to make certain movements to measure range of motion or functional reaching volume, often in common with standard physiological examinations or clinician assessments. One study [11], used a performance task (moving a book from one location to another while seated at a desk) to measure smoothness of motion and identify involuntary movements and dyskinesia. A further study [13] used a machine learning approach to use the 3D movement data to successfully distinguish MS patients from healthy controls.

In general, authors reported good concordance with comparator methodologies.

Olesh et al. [7] reported that reliable estimates were obtained using Kinect when each movement was repeated three times. While traditional subjective clinician ratings typically request only a single repetition of each movement, this may be primarily due to practical time constraints.

Spiromtery
One study [14] investigated the use of a prototype system using four Kinect sensors positioned perpendicularly, each 1 m from the patient, to create a 3D temporal representation of a patient's torso. Spirometry and Kinect data were in good concordance for both Cystic Fibrosis patients and healthy volunteers, based on data from a short performance test requiring the subject to perform quiet breathing for 20 s, followed by a relaxed vital capacity manoeuver (maximum inspiration and expiration) and followed by 20 s of quiet breathing. The authors concluded that their system could accurately assess chest wall motion in human subjects.

Ref	Performance	Measure	Comparator	n	Validation evidence
[14]	Relaxed vital capacity manoeuver	Tidal volume, Respiratory Rate, Minute Ventilation	Spirometry	22	Cystic Fibrosis patients: r>0.8656 Healthy volunteers: r> 0.922

Conclusion

Motion-based video gaming platforms offer potential for low-cost objective assessment of movement and mobility in large-scale clinical trials without reliance on specialist centers. Studies report good validity in some application areas.

Certain measurements may be more suited to the use of this approach. Potential limiting factors include:

- The sampling rate of the camera
- The resolution and the depth/field of vision
- The accuracy of out-of-the-box joint detection algorithms and error correction methods
- The requirement to conduct tests in a confined area (e.g. 0.5 – 4.5 m from the camera).

While findings are promising, the ability to provide the level of accuracy needed in more rapid and finer movements requires more validation work.

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