White Paper: Validity and reliability of Qinematic software

By Glenn Bilby, 20170724

<u>Intended use of Qinematic</u>

Qinematic is intended for use by health and wellness providers who wish to record and visualize basic human movement using a standardized exercise regime and 3D analytics. It is intended to be a semi-automated service whereby end-users can initiate the scan themselves, and get automated feedback about their performance. It does not independently score or rate the performance, nor does it diagnose any problems, however a provider may use the information to assist them in communication and decision making.

The end user must be able to function independently in standing for up to 10 minutes. They must be able to follow video, audio and written instructions. They must have reasonable function in all four limbs. They must be able to stand in the anatomical position, as well as voluntarily cross their arms across the belly. The scan should be performed in a calm, quiet and controlled environment. The user should have access to supervision as required. They should have permission to terminate a test at any time.

<u>The Kinect sensor</u>

There are many studies published about the Kinect sensor and its use in robotics and human movement. Most studies are using the Kinect version 1 sensor and the software development kit (SDK v1), and more recently the Kinect version 2 sensor (+ SDK)[1], which came out in 2014 and is used by Qinematic. Research shows that the version 2 Kinect sensor is more stable, more accurate and more reliable than the version 1 Kinect[2].

The overall lesson from these studies is that Kinect is an acceptable and affordable depth sensor for rehabilitation purposes[3]. There are some challenges with using 1 sensor and no markers, but these can be accommodated by careful selection of tasks recorded, as well as improvements in skeletal tracking algorithms for some body parts. Researchers agree that the ease of use and lower cost of the markerless, the 30 frames per second Kinect sensor is an attractive alternative to the more expensive and inconvenient laboratory optical tracking systems (eg Vicon, Qualisys) that use markers and can scan at 300 frames per second. Although there are some limitations, such as occlusion of body parts during recording, the Kinect sensor may also be more suitable for occupational environments that do not tolerate signal from inertial sensors (such as Xsense)[4]. Both alternatives most certainly improve upon analogue measures performed by a human.

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[1] Reliability and concurrent validity of the Microsoft Xbox One (V2) for assessment of standing balance and postural control
[2] PERFORMANCE EVALUATION OF THE 1ST AND 2ND GENERATION KINECT FOR MULTIMEDIA APPLICATIONS
[3] Use of the Microsoft Kinect system (V2) to characterize balance ability during balance training.
[4] KINEMATIC COMPARISON OF MS KINECT (V1) AND INERTIAL MOTION CAPTURE SYSTEM IN LOAD LIFTING TASK

The measurements can be improved with the use of multiple Kinect cameras attached to multiple computers that integrate the signal for a larger depth cloud. This setup is used in research studies and some film studios, but requires more space and an operator with technical competence. This is impractical for use in health and wellness. Furthermore, the frame rate does not improve, so tasks such as running and golf are not suitable for recording without some post production editing.

Technical considerations

There are 3 primary technical challenges that Qinematic has addressed when using the Kinect sensor:

1. Occlusion is where one body part comes between the sensor and another body part. The latter body part is occluded, and therefore it disappears from the image, making it difficult to track accurately. Qinematic have carefully designed the scan tasks to avoid occlusion.
2. The skeletal tracking can be erratic in some conditions due to environmental factors and choice of clothing. Qinematic control for this at calibration phase. Qinematic also performs a function called smoothing, where fluctuations in data are made less erratic.
3. 3D motion capture files are large, and difficult to manage in real time. Qinematic has a novel way of processing and compressing the data, so that it can be reported immediately after the scan, and the 3D data can be sent via to the internet to/from a cloud library.

There are 3 parts to recognise in the process of recording movement and creating reports with measures:

1. Recording 'point cloud' signal from the Kinect sensor.
   a. The XBox Kinect version 2 sensor is more accurate than the original XBox 360 Kinect sensor. (reference).
2. Applying skeletal tracking to the point cloud data.
   a. Qinematic has created unique tracking algorithms that perform better than the Kinect SDK tracking algorithms that other software is using:
      i. Kinect SDK
         1. Some, but not all of these have been validated for clinical use.
         2. Poor tracking recognised for knee, ankles, head
      ii. Qinematic algorithms improve the stability and accuracy via
         1. Proprietary tracking for
            a. Knees
            b. Ankles
            c. Shoulders
            d. Head

3. Measurement using the XYZ co-ordinates from the skeletal tracking.
    a. Qinematic uses sophisticated mathematics involving non-linear equations, lines of best fit, and principle component analysis. This is the optimal way to benefit from 3D data sets.
    b. Unfortunately, many research studies do not use the same mathematic modelling used by Qinematic, and often use oversimplified models to describe movement (eg. straight line start-end angles, instead of actual trajectory pathways). For example, many studies simply plot a line from start to finish of a movement in just one plane, which does not necessarily reflect the true non-linear trajectory of the body part.

<u>Measurement versus Decision</u>

Qinematic does not score or rate a performance, nor does it give a diagnosis or recommendations. It simply offers qualitative and quantitative information about the performance of an individual during that particular scan. It is the responsibility of the end user or the health provider to interpret results. Qinematic is B2B service to providers who in turn offer a B2C service to end users.

It is the provider's responsibility to confirm that the end user is safe and follows instructions properly, as well as check that the scan data is a reasonable reflection of an actual performance. Measurement error and signal error occur in all optical tracking systems. Qinematic calibrates at the time of starting the software, once again before every scan, and after any time the person leaves the test area and returns to the scan area. To ensure good quality measures, we recommend that the provider checks the point cloud images in Movement Lab, especially if the feedback or the Summary report issued after a scan look like there was an error.

In addition to the limitations of the technical solution (hardware, IT and software), there is some debate about the repeatability or <u>reliability of a performance</u> in humans. This should not be confused with the <u>reliability of the technology</u>. People vary the way they move, and there is no ideal way of moving, especially for activities of daily living. People can achieve goals in various ways. Many consider variation in movement patterns to be positive, to avoid overuse injuries[5]. Many injured populations, like back pain sufferers[6], have less variation in movement patterns. Put simply, moving the same way, like a robot, potentially increases the risk of injury, and makes us ill equipped for uneven terrain and open tasks. This variability has been observed even in simple tasks such as standing posture, single leg balance, side bending, double leg squat and single leg squat.

Regardless, these simple but important activities of daily living (ADL) are routinely measured by health professionals, to make clinical decisions. They are often observed during a single repetition. This might be considered a reflection of real life, where a person is more likely to move spontaneously in response to a cue, rather than repeat movement. Research trials tend to repeat a task, and take the best performance. In clinical practice, the worst performance is more interesting as it is more likely to reflect the mechanism of injury.

Unfortunately, assessment of movement is not routinely documented with any degree of accuracy or impartiality. Therefore, there is little data about norms for both normal populations and special populations. So, what is normal movement, and how should a person's performance be scored?

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[5] Coordinative variability and overuse injury

[6] People with chronic low back pain exhibit decreased variability in the timing of their anticipatory postural adjustments

By scanning millions of people with adequate accuracy and in a standardised way, Qinematic aims to go beyond measuring normal ranges of motion, and categorise movement patterns and movement strategies that belong to normal and specials groups.

An unpublished study performed at Karolinska Institute investigated 3 trials of the Qinematic protocol on novice subjects that were unfamiliar with the exercises (standing posture, single leg balance, side bending, double leg squat and single leg squat) and found that there was a slight difference between trial 1 and trial 2, but no significant difference between trial 2 and trial 3. Based on their recommendations, Posture Scan now asks all subjects to practice the movement along with the instruction video, and then the movement is recorded after a rehearsal.

References:

1. *Clark R et al, Reliability and concurrent validity of the Microsoft Xbox One (V2) for assessment of standing balance and postural control, Gait & Posture 42 (2015) 210-213*

The Kinect V2 includes new and potentially far improved depth and image sensors which may increase its accuracy for assessing postural control and balance. Marker coordinate and joint angle data were concurrently recorded using the Kinect V2 skeletal tracking algorithm and the 3DMA system. Task-specific outcome measures from each system on Day 1 and 2 were compared. Concurrent validity of trunk angle data during the dynamic tasks and anterior-posterior range and path length in the static balance tasks was excellent (Pearson's r>.75). The Kinect V2 has the potential to be used as a reliable and valid tool for the measurement of some aspects of balance performance.

2. *S. Zennaro, M. Munaro, S. Milani, P. Zanuttigh, A. Bernardi, S. Ghidoni, E. Menegatti, PERFORMANCE EVALUATION OF THE 1ST AND 2ND GENERATION KINECT FOR MULTIMEDIA APPLICATIONS, Department of Information Engineering, University of Padova, Italy, 2015*

In this paper, we compared the depth data that can be obtained with the first and second generation of Microsoft Kinect sensors. Kinect v2 proved to be two times more accurate in the near range and even ten times more accurate after 6 meters of distance. Moreover, the new sensor presents an increased robustness to artificial illumination and sunlight. We also verified the performance of Kinect v1 and Kinect v2 in 3D reconstruction and people tracking: the accuracy of both applications significantly improves in different environments with Kinect v2. Further research will be devoted to the evaluation of the sensors performances in proximity of the edges and in dynamic environments. Moreover, we will investigate in which situations Kinect v2 does not provide a reliable depth estimation.

3. *Dohyung Lim, et al , Use of the Microsoft Kinect (V2) system to characterize balance ability during balance training, Clinical Interventions in Aging 2015:10 1077–1083*

Balance training environments commonly involve complex aperiodic movements produced in response to motion generated using a variable basal plane. We have investigated the use

of the Microsoft Kinect depth sensor system to evaluate balance ability. We found that the Kinect system was effective in accurately characterizing changes in the COM and in flexion–extension movements of the lower limbs during balance training. However, we found that the Kinect system was not suitable for use in balance training systems that require in-depth analyses of the joint motions. The Kinect system is therefore expected to be useful for balance training systems that require characterization of the changes in the COM and the joint angles during flexion–extension movements

4. P. STREIT et al, <u>KINEMATIC COMPARISON OF MS KINECT (V1) AND INERTIAL MOTION CAPTURE SYSTEM IN LOAD LIFTING TASK</u>, Congress of the International Society of Biomechanics 2013, Brazil

Considering the motion captures were held in a controlled environment, MS Kinect through iPiSoft results have shown that, under these circumstances, product analyses and motion capturing for other purposes can be performed by MS Kinect. It is recommended to avoid large objects or activities that imply any sort of occlusion by the consoles. Further analyses of this experiment are being conducted in order to produce statistical results from motion-captured data and more detailed conclusion. Motion captures of the study case based on the EWA are currently being held.

5. Clark RA1, Pua YH, Fortin K, Ritchie C, Webster KE, Denehy L, Bryant AL. <u>Validity of the Microsoft Kinect (V1) for assessment of postural control. Gait Posture</u>. 2012 Jul;36(3):372-7. doi: 10.1016/j.gaitpost.2012.03.033. Epub 2012 May 23.

Clinically feasible methods of assessing postural control such as timed standing balance and functional reach tests provide important information, however, they cannot accurately quantify specific postural control mechanisms. The Microsoft Kinect™ V1 system provides real-time anatomical landmark position data in three dimensions (3D), and given that it is inexpensive, portable and simple to setup it may bridge this gap. This study assessed the concurrent validity of the Microsoft Kinect™ against a benchmark reference, a multiple-camera 3D motion analysis system, in 20 healthy subjects during three postural control tests: (i) forward reach, (ii) lateral reach, and (iii) single-leg eyes-closed standing balance. For the reach tests, the outcome measures consisted of distance reached and trunk flexion angle in the sagittal (forward reach) and coronal (lateral reach) planes. For the standing balance test the range and deviation of movement in the anatomical landmark positions for the sternum, pelvis, knee and ankle and the lateral and anterior trunk flexion angle were assessed. The Microsoft Kinect™ and 3D motion analysis systems had comparable inter-trial reliability (ICC difference=0.06±0.05; range, 0.00-0.16) and excellent concurrent validity, with Pearson's r-values >0.90 for the majority of measurements (r=0.96±0.04; range, 0.84-0.99). However, ordinary least products analyses demonstrated proportional biases for some outcome

measures associated with the pelvis and sternum. These findings suggest that the Microsoft Kinect™ can validly assess kinematic strategies of postural control. Given the potential benefits it could therefore become a useful tool for assessing postural control in the clinical setting.

6. Joseph Hamill et al, Coordinative variability and overuse injury, Sports Med Arthrosc Rehabil Ther Technol. 2012; 4: 45.

Consistently, we have found that the higher variability state of a coordinative structure is the healthy state while the lower variability state is the unhealthy or pathological state. It is clear that very high coordinative variability could also result in injury and that there must be a window of 'higher variability' in which non-injured athletes function. While this finding that coordinative variability is functional has been shown in several studies, it is still not clear if reduced variability contributes to or results from the injury.

7. Jacobs et al, People with chronic low back pain exhibit decreased variability in the timing of their anticipatory postural adjustments, Behav Neurosci. 2009 Apr; 123(2): 455–458.

Variability in the constituents of movement is fundamental to adaptive motor performance. A sustained decrease in the variability of anticipatory postural adjustments (APAs) occurs when performing cued arm raises following acute, experimentally induced low back pain (LBP) [Moseley and Hodges, 2006, Behavioral Neuroscience, 120, 474–476]. This observation implies these changes in variability may also be relevant to people with chronic LBP. To confirm that this reduced variability in the timing of APAs is also evident in people with chronic LBP, we examined the standard deviations of electromyographic onset latencies from the bilateral internal oblique (IO) and erector spinae muscles (relative to deltoid muscle onset) when 10 people with chronic LBP and 10 people without LBP performed 75 trials of rapid arm raises. The participants with LBP exhibited significantly less variability of their IO muscle onset latencies, confirming that the decreased variability of postural coordination that is evident following acutely induced LBP is also evident in people with chronic LBP. Thus, people with chronic LBP may be less capable of adapting their APAs to ensure postural stability during movement.

Accuracy and Reliability of the Kinect Version 2 for Clinical Measurement of Motor Function

Karen Otte , Bastian Kayser, Sebastian Mansow-Model, Julius Verrel, Friedemann Paul, Alexander U. Brandt, Tanja Schmitz-Hübsch (2016, Nov 2016)

Results

Accuracy of Kinect V2 landmark movements was moderate to excellent and depended on movement dimension, landmark location and performed task. Signal to noise ratio provided information about Kinect V2 landmark stability and indicated larger noise behaviour in feet and ankles. Most of the derived clinical parameters showed good to excellent absolute agreement (30 parameters showed ICC(3,1) > 0.7) and consistency (38 parameters showed r > 0.7) between both systems.

Conclusion

Given that this system is low-cost, portable and does not require any sensors to be attached to the body, it could provide numerous advantages when compared to established marker- or wearable sensor based system. The Kinect V2 has the potential to be used as a reliable and valid clinical measurement tool.

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166532

Evaluation of the Microsoft Kinect as a clinical assessment tool of body sway.

Yeung LF[1], Cheng KC[2], Fong CH[1], Lee WC[1], Tong KY[3].

Total body center of mass (TBCM) is a useful kinematic measurement of body sway. However, expensive equipment and high technical requirement limit the use of motion capture systems in large-scale clinical settings. Center of pressure (CP) measurement obtained from force plates cannot accurately represent TBCM during large body sway movement. Microsoft Kinect is a rapidly developing, inexpensive, and portable posturographic device, which provides objective and quantitative measurement of TBCM sway. The purpose of this study was to evaluate Kinect as a clinical assessment tool for TBCM sway measurement. The performance of the Kinect system was compared with a Vicon motion capture system and a force plate. Ten healthy male subjects performed four upright quiet standing tasks: (1) eyes open (EOn), (2) eyes closed (ECn), (3) eyes open standing on foam (EOf), and (4) eyes closed standing on foam (ECf). Our results revealed that the Kinect system produced highly correlated measurement of TBCM sway (mean RMSE=4.38 mm; mean CORR=0.94 in Kinect-Vicon comparison), as well as comparable intra-session reliability to Vicon. However, the Kinect device consistently overestimated the 95% CL of sway by about 3mm. This offset could be due to the limited accuracy, resolution, and sensitivity of the Kinect sensors. The Kinect device was more accurate in the medial-lateral than in the anterior-posterior direction, and performed better than the force plate in more challenging balance tasks, such as (ECf) with larger TBCM sway. Overall, Kinect is a cost-effective alternative to a motion capture and force plate system for clinical assessment of TBCM sway.

https://www.ncbi.nlm.nih.gov/pubmed/25047828

Accuracy and repeatability of joint angles measured using a single camera markerless motion capture system.

Schmitz A[1], Ye M[2], Shapiro R[3], Yang R[2], Noehren B[4].

Markerless motion capture systems have developed in an effort to evaluate human movement in a natural setting. However, the accuracy and reliability of these systems remain understudied. Therefore, the goals of this study were to quantify the accuracy and repeatability of joint angles using a single camera markerless motion capture system and to compare the markerless system performance with that of a marker-based system. A jig was placed in multiple static postures with marker trajectories collected using a ten camera motion analysis system. Depth and color image data were simultaneously collected from a single Microsoft Kinect camera, which was subsequently used to calculate virtual marker trajectories. A digital inclinometer provided a measure of ground-truth for sagittal and frontal plane joint angles. Joint angles were calculated with marker data from both motion capture systems using successive body-fixed rotations. The sagittal and frontal plane joint angles calculated from the marker-based and markerless system agreed with inclinometer measurements by <0.5°. The systems agreed with each other by <0.5° for sagittal and frontal plane joint angles and <2° for transverse plane rotation. Both systems showed a coefficient of reliability <0.5° for all angles. These results illustrate the feasibility of a single camera markerless motion capture system to accurately measure lower extremity kinematics and provide a first step in using this technology to discern clinically relevant differences in the joint kinematics of patient populations.