BJO Online First, published on June 11, 2014 as 10.1136/bjophthalmol-2014-305095

Validity and reliability of head posture measurement using Microsoft Kinect

Baek-Lok Oh,[1] Jongmin Kim,[2] Jongshin Kim,[3] Jeong-Min Hwang,[1] Jehee Lee[2]

▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjophthalmol-2014-305095).

[1]Department of Ophthalmology, Seoul National University College of Medicine, Seoul National University Bundang Hospital, Seognam, Korea
[2]School of Computer Science and Engineering, Seoul National University, Seoul, Korea
[3]Graduate School of Medical Science and Engineering, KAIST, Daejeon, Korea

Correspondence to
Dr Jeong-Min Hwang, Department of Ophthalmology, Seoul National University College of Medicine, Seoul National University Bundang Hospital, 166 Gumi-ro Bundang-gu, Seognam, Gyeonggi-do 463-707, Korea; hjm@snu.ac.kr
Jehee Lee, PhD, School of Computer Science and Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Korea; jehee@cse.snu.ac.kr

B-LO and JK contributed equally to the work and should be considered equivalent first authors.J-MH and JL contributed equally to the work and should be considered equivalent corresponding authors.

Received 20 February 2014
Revised 5 May 2014
Accepted 19 May 2014

ABSTRACT

Aims To investigate the validity and reliability of Microsoft Kinect-based head tracker (KHT) for measuring head posture.

Methods Considering the cervical range of motion (CROM) as a reference, one-dimensional and three-dimensional (1D and 3D) head postures of 12 normal subjects (28–58 years of age; 6 women and 6 men) were obtained using the KHT. The KHT was validated by Pearson's correlation coefficient and intraclass correlation (ICC) coefficient. Test–retest reliability of the KHT was determined by its 95% limit of agreement (LoA) with the Bland-Altman plot. Face recognition success rate was evaluated for each head posture.

Results Measurements of 1D and 3D head posture performed using the KHT were very close to those of the CROM with correlation coefficients of 0.99 and 0.97 ($p<0.05$), respectively, as well as with an ICC of >0.99 and 0.98, respectively. The reliability tests of the KHT in terms of 1D and 3D head postures had 95% LoA angles of approximately ±2.5° and ±6.5°, respectively.

Conclusions The KHT showed good agreement with the CROM and relatively favourable test–retest reliability. Considering its high performance, convenience and low cost, KHT could be clinically used as a head posture-measuring system.

Anomalous head posture (AHP) is an important sign of various diseases, including strabismus, nystagmus, ptosis, visual field defect and refractive errors.[1 2] Reliable quantitative measurement of AHP is critical for evaluating the change in AHP after the treatment of an ocular disease and for determining a surgical plan for patients with ocular torticollis.[3 4] However, currently there is no method for AHP measurement that can be adopted for widespread use in clinical settings.

Since Kushner documented that the cervical range of motion (CROM; Performance Attainment Associate, St. Paul, Minnesota, USA) might be useful for measuring head posture,[5] several studies have been undertaken to develop more accessible head posture measurement devices with clinically acceptable validity and reliability.[6 7] Hald *et al*[6] showed that the head posture of patients could be evaluated accurately with a motion tracker-based system (InterSense, Inc., Billerica, Massachusetts, USA). However, this motion tracker should be placed on the subject's head; furthermore, this system was too expensive (>US$2000). Recently, Kim *et al*[7] developed a system; an infrared optical head tracker using two Nintendo Wii remote controllers (WiiMote; Nintendo Co., Ltd. Kyoto, Japan). This system showed strong concordance with the CROM, had relatively good test–retest reliability and was much cheaper than Hald's system. Nonetheless, patients were required to wear a device on their head, and examiners needed to set virtual 3-D space before measurement. The common disadvantage of all such head posture measurement systems is that subjects are required to wear a head-mounted device, and thus, we need hardware that is contact-free and easy to setup and offers good efficacy as compared with previous systems. In this study, we developed a digital head posture measurement system incorporating Microsoft Kinect (Microsoft Corp., Bellevue, Washington, USA)—Kinect head tracker (KHT)—and evaluated its validity and reliability in one dimension and three dimensions (1D and 3D) in comparison with the CROM device.

METHODS

Subjects

Twelve adult subjects (28–58 years of age; six women and six men) with normal vision and head posture participated in this study after ocular examination by two trained ophthalmologists (J-MH, B-LO). The study protocol complied with the Declaration of Helsinki and was approved by the Institutional Review Board of Seoul National University Bundang Hospital (B-1210-173-010). Informed consent was obtained from all subjects after the details of the study were explained.

Kinect head tracker

The KHT system consists of a depth camera (Microsoft Kinect), a desktop computer and a software for data analysis and visualisation (figure 1A).

The Face-Tracking Software Development Kit for the Kinect (Face Tracking SDK; Microsoft Corp., Bellevue, Washington, USA) enables us to track subject's face in real time. The system tracks 87 important 2D points (eg, centre of eye, corners of the mouth and centre of the nose) on an image by following an active appearance model-based approach, a recently developed facial tracking algorithm in the field of computer vision.[8] A computed 3D mask (figure 1B–D) fits a subject's face and is deformed based on facial movements. A face-tracking module continuously measures and displays a subject's head posture at a rate of 30 Hz. We extensively modified the Face Tracking SDK for extracting Euler angles from 3D mask and for implementing a zero-calibration function, as described in online supplementary appendix.

Cervical range of motion

The CROM device consists of three indicators; two inclinometers, and one compass that respond to a shoulder-mounted magnetic yoke. In this study, to

To cite: Oh B-L, Kim J, Kim J, *et al*. *Br J Ophthalmol* Published Online First: [*please include* Day Month Year] doi:10.1136/bjophthalmol-2014-305095

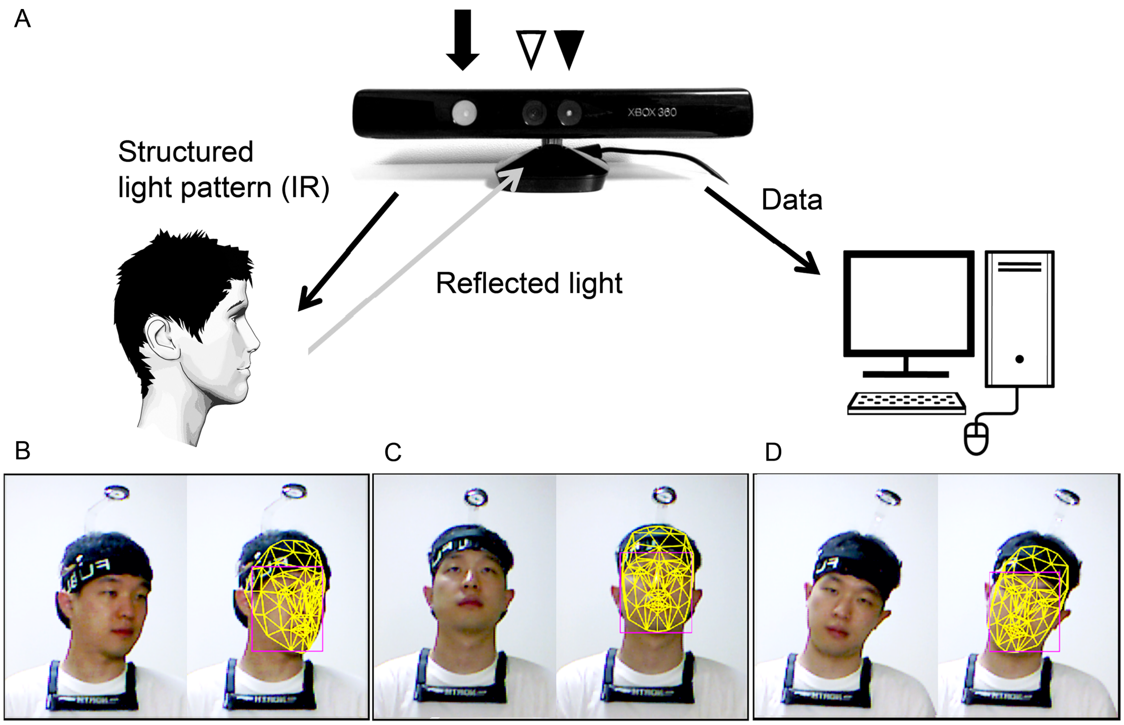

Figure 1 Schematic drawing of Kinect head tracker (KHT) system. (A) An infrared laser projector (black arrow) produces a structured light pattern in a face, which is captured by the CMOS camera (black arrowhead). Given input data from CMOS and RGB camera (empty arrowhead), the head posture of a subject is calculated by the personal computer. (B–D) Examples of images of left head turn (B), chin up (C) and left head tilt–lateral tilt (D).

minimise possible interference of the front indicator on the KHT's facial recognition output, we requested the subjects to wear the CROM device on the back of their heads.

Procedure

The distance from the KHT to the subject's heads was set to 1 m, and the level of the Kinect sensor was adjusted to that of the subject's noses. The subjects did not receive any angle output feedback to avoid bias resulting from subject self-adjustment.

Face recognition rate

The face recognition by KHT was recorded for each head posture. Data of face recognition rate <50% for a given head posture were excluded from further evaluation of validity and reliability of KHT measurement.

Validity and reliability tests of KHT for 1D head postures

Agreement between the KHT and the CROM measurements was assessed, and the test–retest reliability of the KHT was evaluated. The 1D posture of the subject head ranged from −30° to 30°, −30° to 30° and −40° to 40° for head turn, chin up/down and lateral tilt, respectively. Head movement was recorded in increments of 10° in all directions. Two tests were performed for each head posture. The measured angles were rounded off to the nearest integer values. Examiner aligned subject's heads to the neutral posture at the beginning of each trial.

Validity and reliability tests of KHT for 3D head postures

In the 3D head posture tests, subjects' heads were rotated in combination of the same degree of head turn, chin up/down and lateral tilt in 10° increments up to 30° in all eight directions (four quadrants with right and left head tilt in each quadrant). Each head posture was tested twice for a total of 96 head postures in 8 directions. Otherwise, the settings were identical to those for the 1D head posture measurement.

Data analysis

Pearson's and intraclass correlation coefficients (ICC) of the exact type for the two-way mixed model between KHT and CROM were computed over the range of angles measured in each posture. The test–retest repeatability of head postures in KHT data was determined using 95% limits of agreement (LoA) and represented in the form of Bland–Altman plots. The results were interpreted as statistically significant at $p<0.05$ (GraphPad Prism5; GraphPad Software, Inc., San Diego, California, USA).

RESULTS

Face recognition rate in 1D posture

For 1D head postures, face recognition at every head posture (≤30° in head-turn and head-tilt, ≤40° in head tilt) was successful for 12 subjects.

Validity of KHT in 1D postures

For head turn (figure 2A), chin up/down (figure 2B) and lateral tilt (figure 2C), the KHT and CROM measurements were highly correlated ($r>0.998$, $p<0.001$; $r=0.997$, $p<0.001$; $r=0.999$, $p<0.001$, respectively) and in good agreement ($ICC>0.997$; $ICC=0.997$; $ICC=0.999$, respectively).

The mean angular difference at each position varied from 0° to 0.88° for head turn, 0.25° to 2.50° for chin up/down and 0.04° to1.75° for lateral tilt.

The standard deviation (SD) at each position ranged from 0.87° to 2.35° for head turn, 0.59° to 1.89° for chin up/down and 0.51° to 1.20° for lateral tilt.

 Oh B-L, *et al*. *Br J Ophthalmol* 2014;**0**:1–5. doi:10.1136/bjophthalmol-2014-305095

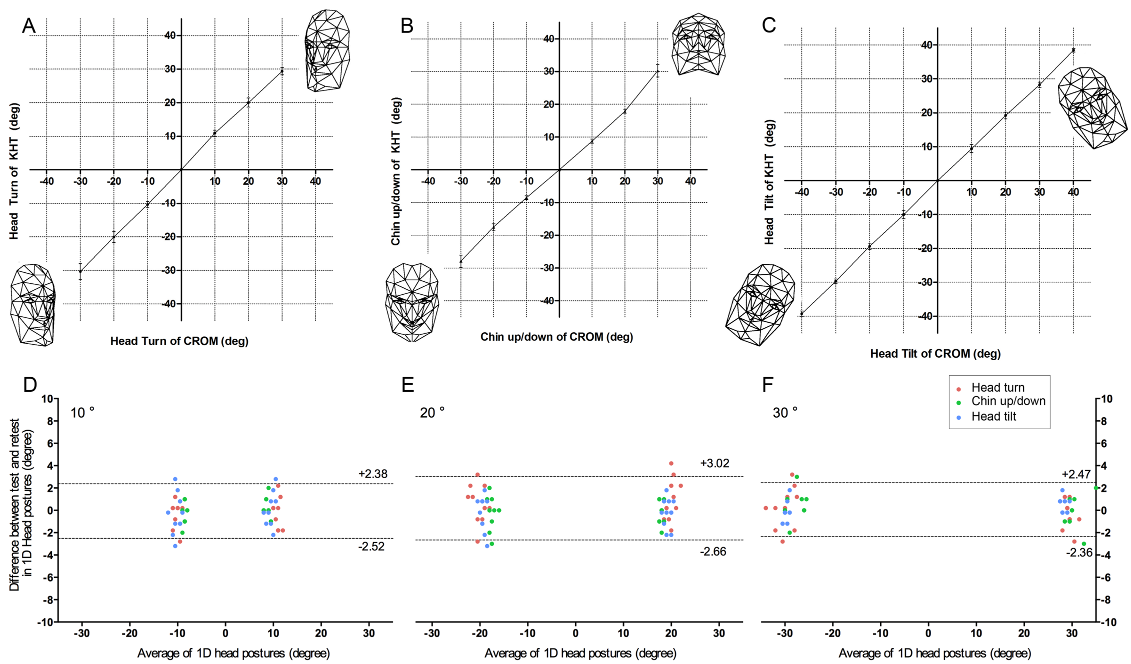

Figure 2 Results of validity and reliability analysis of Kinect head tracker (KHT) compared with cervical range of motion (CROM) for one-dimensional (1D) head postures. (A–C) The relationship between the measurements of the KHT and the CROM correlated highly for all three head movements (r=0.997, p<0.001). (D–E) Bland–Altman plot showing reliability for 1D postures between test and retest. The upper and lower dotted lines represent the 95% limit of agreement. To visualise the overlapped points, the points of data of head turn and head tilt were nudged +0.2° and −0.2°, respectively, along the y-axis.

Reliability of KHT for 1D postures

The 95% LoA were obtained for two tests of 12 normal adult subjects (figure 2D–F). As shown in this figure, the 95% LoA range was −2.52 to +2.38° for the 10° 1D head posture (figure 2D), −2.66 to +3.02° for the 20° head posture (figure 2E) and −2.36 to +2.47° for the 30° head posture (figure 2F).

Face recognition rate for 3D postures

In the 3D head posture, the face recognition rate results are 100% below 30°. However, for posture 30°, the facial recognition rate decreased; 88% for right turn, chin up, right tilt; 4% for right turn, chin up, left tilt; 25% for left turn, chin up, right tilt; 75% for left turn, chin up, left tilt; 33% for right turn, chin up, right tilt; 0% for other three movements. In the following analyses, data of the postures for which facial recognition rates were lower than 50% were discarded.

Validity of KHT for 3D postures

For head turn (figure 3A), chin up/down (figure 3B) and lateral tilt (figure 3C), analysis of 3D head postures showed a high correlation (r>0.974, p<0.001; r=0.974, p<0.001; r=0.979, p<0.001, respectively) and good agreement (ICC>0.986; ICC=0.990; ICC=0.988, respectively) between the KHT and CROM measurements.

The mean angular difference at each position varied from 0.04° to 5.75° for head turn, 0.17° to 5.39° for chin up/down and 0.04° to 6.95° for lateral tilt.

The standard deviation at each position ranged from 0.98° to 0.45° for head turn, 0.64° to 3.12° for chin up/down and 0.72° to 5.04° for lateral tilt.

Reliability of KHT for 3D postures

The 95% LoA were obtained from two tests of 12 normal adult subjects. The range of 95% LoA was approximately from −5° to +5° (for 10°, figure 3D), −3.88° to 3.74° (for 20°, figure 3E), −5.30° to +4.98° (for 30°, figure 3F), −5.78° to 6.57°.

DISCUSSION

In this study, we investigated the possibility of adapting a contact-free 3D camera (Microsoft Kinect) for evaluating AHP in a clinical setting. In normal subjects, this system showed good concordance with the CROM measurements and relatively good test–retest reliability in measuring head postures.

Head posture measurement has been studied extensively in the field of computer vision. As 3D camera, Microsoft Kinect, a controller-free gaming device interface, is one of the state-of-the-art depth-sense technology devices capable of documenting human body motion, including head posture.[9 10]

In the clinical evaluation of AHP, many clinicians continue to use rough visual estimation with a substantial range of error.[11] For increasing the precision of head posture measurements, several systems including those that use analogue technologies such as inclinometric[5 12] or photographic[13 14] methods and digital technologies such as motion tracker[6] or infrared sensor[7] have been proposed. However, all these systems have some limitations that hamper their wide adoption in clinical practice. The requirements of head posture measurement systems to be used easily in a clinical setting include the following: (1) an ability to obtain instantaneous and reliable measurements of three-axis head rotation, (2) low system price, (3) ease of setting and initiating measurement and (4) patient comfort, such as contact-free use. Recently, Microsoft Kinect has attracted considerable attention and has been used in medical practices such as orthopaedics and rehabilitation clinics for evaluating the musculoskeletal status of extremities.[15–17] We assumed that head posture measurement using Kinect can be an alternative to the methods currently followed in medical practice. However to the best of our knowledge, the application of Kinect to head

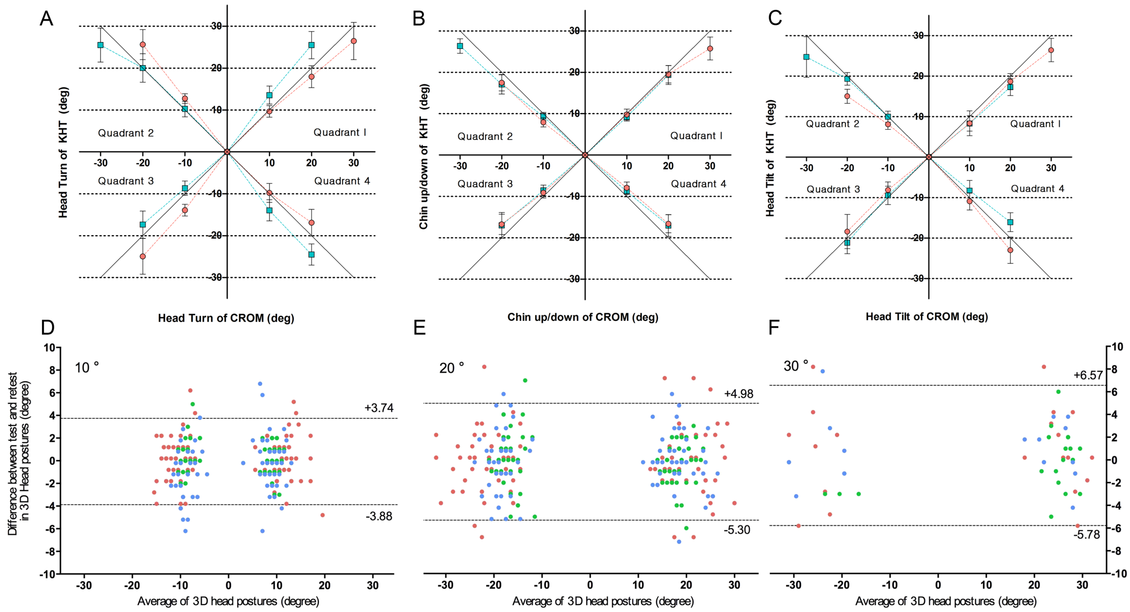

Figure 3 Results of validity and reliability analysis of Kinect head tracker (KHT) compared with cervical range of motion (CROM) for three-dimensional head postures. (A) Results of head turn. Data for right head turn are represented in the right side of the plot (quadrants 1 and 4); data for left head turn are displayed in the left side of the plot (quadrants 2 and 3). (B) Results of chin up/down. Data for chin up are depicted in the upper part of the plot (quadrants 1 and 2); data for chin down are represented in the lower part of the plot (quadrants 1, 3 and 4). (C) Results of head tilt. Note that although the data are located in all four quadrants in accordance with the direction of head turn and chin up/down, values of x- and y-axes are the measurements of CROM and KHT for each rotation, respectively. (D–F) Bland–Altman plots showing test–retest reliability. Upper and lower dotted lines represent 95% limit of agreement.

posture measurement has not been reported yet. Therefore, we investigated the possibility of using Microsoft Kinect for measuring AHP by assessing its validity and reliability.

In 1D measurements, the outputs of the KHT were very close to those of the CROM (ICC>0.997). The mean angular difference between the two devices and standard deviation was <3°s, respectively. In 3D measurements, the strength of correlation and agreement between the KHT and the CROM were less than that in the 1D measurement, but the level of agreement remained good (ICC>0.986). The mean angular difference between the two devices was <6.9°, which is slightly larger than those of Kim's device[7] and Hald's device,[6] respectively. However, the mean angular difference between the two devices was <5.6° for head postures of ≤20°. A possible explanation for this difference could be inaccurate rotations of the human heads owing to the continuous slight movements of subjects' heads during simultaneous reading of the three CROM indicators. Another explanation could be an error in 3D mask-fitting process for large rotation angles because Microsoft Kinect needs an appropriate visual input of the subject's face to determine the head posture.

Additionally, we fitted a linear model to the KHT outputs as a function of the CROM outputs for three rotations measurements (see online supplementary appendix) because the measurement errors showed a linear relationship with the size of the rotations. After correction using this linear relationship, the KHT outputs were very close to the CROM outputs (figure 4). This result implied that the measurement errors can be corrected through software calibration for further application of the KHT.

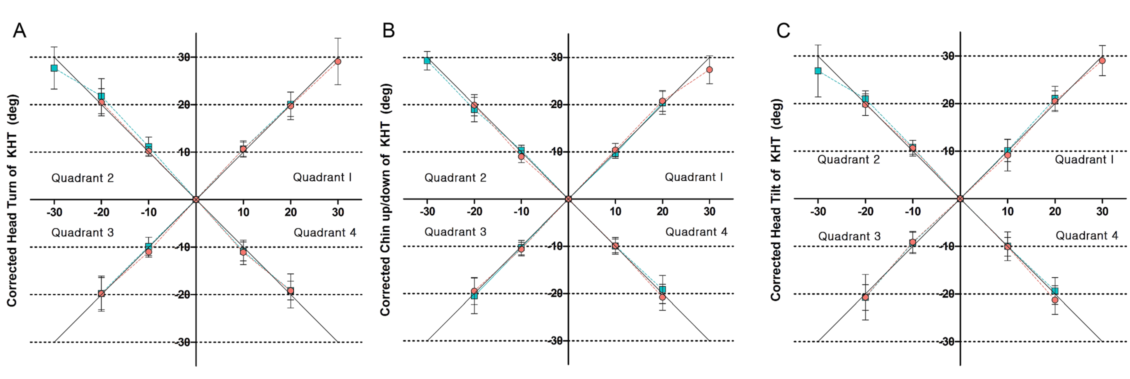

Figure 4 Corrected outputs of Kinect head tracker (KHT) for three-dimensional postures. (A) Head turn. Data for right head turn are represented in the right side of the plot (quadrants 1 and 4); data for left head turn are displayed in the left side of the plot (quadrants 2 and 3). (B) Chin up/down, Data for chin up are depicted in the upper part of the plot (quadrants 1 and 2); data for chin down are represented in the lower part of the plot (quadrants 1, 3 and 4). (C) Head tilt. Note that although the data are located in all four quadrants in accordance with the direction of head turn and chin up/down, values of x- and y-axes are the measurements of cervical range of motion and KHT for each rotation, respectively.

Regarding the test–retest reliability of the KHT, the range of 95% LoA of 3D head positions was about ±4.0° for the 10° head posture, ±5.0° for the 20° head posture and approximately ±6.0° for the 30° head posture, which are comparable to those of Kim's device[7] and Hald's device.[6] In particular, for three rotations of 30°, the range of 95% LoA of head tilt showed the largest reliability range of ±8.0°. Interestingly, this finding was also observed in Hald's[6] and Kim's[7] reports. Although reading difficulties or errors from the protractors were suggested as the source of errors of the large variability in head tilt, there may be some common intrinsic factor among these systems and the KHT. Further studies may be necessary to verify this hypothesis.

KHT has several advantages over previous head posture measurement systems. First, KHT has some features of a digital device: instantaneous and simultaneous measurement of three rotation angles, easy calibration for zero-calibration and independence from the Earth's magnetic force. On the contrary, the subject should face the true magnetic north or mount a magnet yoke to minimise interference between the Earth's magnetic field in the CROM device. Second, KHT can be set up within a reasonable cost. The total manufacturing cost of KHT was approximately $100 (for Microsoft Kinect, excluding the cost of the personal computer), whereas the motion tracking used in Hald's system[6] is considerably more expensive (>US$2000). Third, setting the virtual 3D space before the measurement was not necessary with the KHT in contrast to Kim's device.[7] Fourth, and most important, the KHT system is controller-free, and subjects need not wear or mount any device. This feature could be very helpful in measuring the head posture of uncooperative children.

KHT has a few limitations. First, it has a restricted range of head posture measurement because depth camera needs an appropriate visual input of the subject's face to determine his/her head posture. In the case of AHP of over 30° or AHP with multiple rotation components (eg, 30° head posture in 3D head posture in this study), the KHT can have a large measuring error. However, according to a recent study,[18] using multiple KHTs would solve this problem since failure of one KHT can be compensated by the others. Second, when the distance between the KHT and the patient's head is increased, the depth error that can negatively affect the accuracy of the KHT is proportional to the square of the distance. Although we set the distance to 1 m in our experiments, further study is needed to evaluate the effect of the distance on the reliability of the KHT. Third, we did not investigate the validity and reliability of the KHT in patients with AHP, especially in patients with facial deformities or different facial configurations such as those of very young children. Further studies might be necessary for these groups of patients.

In conclusion, KHT showed good agreement with the CROM and relatively favourable reliability. Considering its contact-free operation, high performance and low cost, KHT could be used clinically as a quantitative head posture measuring system for patients with AHP.

Contributors B-LO, J-MH and JL were responsible for conception and design. B-LO, JmK and JsK were responsible for analysis, interpretation of data and drafting the article. J-MH and JL were responsible for revising the draft critically for important intellectual content. All authors approved the final version of the manuscript to be published.

Funding This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT, and Future Planning (No. 2013R1A1A2010606, No. 2011-0018340 and No. 2007-0056094).

Competing interests None.

Patient consent Obtained.

Ethics approval The Institutional Review Board of Seoul National University Bundang Hospital.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1. Nucci P, Kushner BJ, Serafino M, *et al*. A multi-disciplinary study of the ocular, orthopedic, and neurologic causes of abnormal head postures in children. *Am J Ophthalmol* 2005;140:65–8.
2. Mitchell PR. Ocular torticollis. *Trans Am Ophthalmol Soc* 1999;97:697–769.
3. Hertle RW, Dell'Osso LF, FitzGibbon EJ, *et al*. Horizontal rectus muscle tenotomy in children with infantile nystagmus syndrome: a pilot study. *J AAPOS* 2004;8:539–48.
4. Yang D, Hertle RW, Hill VM, *et al*. Gaze-dependent and time-restricted visual acuity measures in patients with Infantile Nystagmus Syndrome (INS). *Am J Ophthalmol* 2005;139:716–18.
5. Kushner BJ. The usefulness of the cervical range of motion device in the ocular motility examination. *Arch Ophthalmol* 2000;118:946–50.
6. Hald ES, Hertle RW, Yang D. Development and validation of a digital head posture measuring system. *Am J Ophthalmol* 2009;147:1092–100, 1100 e1091–3.
7. Kim J, Nam KW, Jang IG, *et al*. Nintendo Wii remote controllers for head posture measurement: accuracy, validity, and reliability of the infrared optical head tracker. *Invest Ophthalmol Vis Sci* 2012;53:1388–96.
8. Mingcai Z, Lin L, Jian S, *et al*. AAM based face tracking with temporal matching and face segmentation. *Computer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference on*, 2010:701–8.
9. Zhengyou Z. Microsoft Kinect sensor and its effect. *MultiMedia, IEEE* 2012;19:4–10.
10. Cai Q, Gallup D, Zhang C, *et al*. 3D deformable face tracking with a commodity depth camera. In: Daniilidis K, Maragos P, Paragios N.eds *Computer Vision—ECCV 2010*. Berlin Heidelberg: Springer, 2010:229–42.
11. Kim DS, Coats DK, McCreery KM, *et al*. Accuracy of clinical estimation of abnormal head postures. *Binocul Vis Strabismus Q* 2004;19:21–4.
12. Murphy KE, Preston CB, Evans WG. The development of instrumentation for the dynamic measurement of changing head posture. *Am J Orthod Dentofacial Orthop* 1991;99:520–6.
13. Ferrario VF, Sforza C, Germano D, *et al*. Head posture and cephalometric analyses: an integrated photographic/radiographic technique. *Am J Orthod Dentofacial Orthop* 1994;106:257–64.
14. Young JD. Head posture measurement. *J Pediatr Ophthalmol Strabismus* 1988;25:86–9.
15. Clark RA, Pua YH, Fortin K, *et al*. Validity of the Microsoft Kinect for assessment of postural control. *Gait Posture* 2012;36:372–7.
16. Chang YJ, Han WY, Tsai YC. A Kinect-based upper limb rehabilitation system to assist people with cerebral palsy. *Res Dev Disabil* 2013;34:3654–9.
17. Bo AP, Hayashibe M, Poignet P. Joint angle estimation in rehabilitation with inertial sensors and its integration with Kinect. *Conf Proc IEEE Eng Med Biol Soc* 2011;2011:3479–83.
18. Muñoz-Salinas R, Yeguas-Bolivar E, Saffiotti A, *et al*. Multi-camera head pose estimation. *Mach Vision Appl* 2012;23:479–90.

BJO

Validity and reliability of head posture measurement using Microsoft Kinect

Baek-Lok Oh, Jongmin Kim, Jongshin Kim, et al.

Br J Ophthalmol published online June 11, 2014
doi: 10.1136/bjophthalmol-2014-305095