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ORIGINAL RESEARCH

Accuracy and Correlation of the Kinect-Based Semi-Automatic Scoring Method for Measuring Anomalous Head Posture as Compared to the CROM® Device

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Objective: To determine the reliability of the Kinect-based semi-automatic scoring method (KSSM) using Kinect for Windows v2 for head posture compared to the cervical range-of-motion (CROM) device.

Methods and Analysis: Head positions between −40° and +40° of chin up/down (X), head turn (Y), and lateral tilt (Z) were measured in 10° increments in healthy volunteers. Their head positions were simultaneously measured using the KSSM and CROM. The following four points were analyzed: the success rate of the KSSM, the correlation between the two methods, the comparison of results by 95% limits of agreement (LA), and proportional error at 95% LA.

Results: The measurability of the KSSM for all positions within ±30° of the X, Y, and Z axes was 100%. The correlations for both methods were 0.979 (95% CI: 0.967–0.987), 0.985 (0.976–0.991), and 0.988 (0.981–0.993) for the X-, Y-, and Z-axes, respectively. The simple linear regression analysis equations for 95% LA were Y=−0.024X-0.452 for X axes, Y=0.024X-0.363 for Y axes, and Y= −0.045X+0.217 for Z axes (95% confidence interval for each axis: −0.055–0.007, −0.006–0.050, and −0.071–0.018). However, the proportional biases were small because the predictive values of the differences in head positions from −40° to 40° determined by the equations were within ± 5° for chin up/down and within ± 3° for head tilt.

Conclusion: Head posture measurements using the KSSM and CROM were found to be similar when used in clinical settings.

Keywords: anomalous head posture, Kinect, CROM, spine, reliability

Introduction

In ophthalmology, a normal head position is a state wherein the face faces straight toward the object when looking at it. A normal head position is important for normal skeletal growth during childhood. Anomalous head posture (AHP) is a complication that needs to be treated or prevented from occurring in orthopedic diseases, such as scoliosis and congenital torticollis, and in ophthalmologic disorders, including some forms of strabismus, nystagmus, blepharoptosis, visual field defects, and refractive errors.[1–6] To estimate the therapeutic effect of AHP, it is very important to be able to measure the head position angle before and after treatment quantitatively.

AHP is widely evaluated by taking pictures of the head position in front of a wall chart with meridian lines positioned every 10°. Although it is easy to measure head tilt using this method, it requires taking photographs of the head positions from the side and above to assess the chin up/down and head (face) turns.6 As AHP assessment needs to be based on records of three-dimensional (3D) head postures, this method cannot be used to measure AHP. Moreover, it is difficult for children to

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take pictures from multiple directions, as this requires maintaining the same position for a long period of time. Recently, Farah et al reported an AHP measurement method that uses a smartphone as an assessment tool.[7] However, 3D head posture pictures cannot be taken at the same time when using this method; thus, the same difficulties are yet to be resolved.

In 2000, Kushner reported that the cervical range of motion (CROM) (Performance Attainment Associate, St. Paul, MN, USA) might be a useful tool for head posture measurements.[8] Subsequently, several studies, primarily from Europe and North America, have demonstrated that CROM is a highly reproducible and useful device for head posture measurements with clinically acceptable validity and reliability.[9–12] The CROM device is secured similarly to a head-mounted camera and is firmly fixed to the head to prevent any shifting. However, this positioning technique occasionally makes it difficult to reproduce and maintain the same attached head position as without the device. Furthermore, it can be difficult to fit CROM securely in children, as the size is designed for adults. Recently, the use of electronic AHP measuring devices with head-mounted motion trackers or an infrared head tracker has been reported to achieve more accurate head posture measurements.[13,14] However, both methods require head-mounted equipment, which risks altering the head posture and restricts its use to adults and compliant children. Therefore, several recent studies have examined the development of a method that does not require a device to be attached to the head, including measuring the head position using a Vicon motion capture system (Vicon Motion System Ltd., Oxford, UK),[15] Cambridge Face Tracker (Carl Zeiss Meditec, Jena, Germany)[16] or Kinect (Microsoft Corp., Bellevue, WA).[17–19]

Although reliable head position results can be obtained when using the Vicon motion capture system, this method requires attaching eight reflective markers to the body, head, and face surfaces, and the use of nine infrared cameras for analysis of the collected images. Therefore, a large space is necessary, and the Vicon system is too expensive to be introduced within routine clinical settings.[15] Thomas et al reported on the effectiveness and accuracy of the Cambridge Face Tracker, allowing useful quantification of head posture in real-time or from pre-captured video.[16] This system has significant advantages over other approaches, such as CROM, as patients do not need to wear any apparatus and are inexpensive. However, this system requires expertise in routine clinical settings.

A leading markerless tracking method using a low-cost, portable motion-sensing device, Microsoft Kinect (Microsoft Corporation, Bellevue, WA), in combination with Microsoft's Face Tracking Software Development Kit, has recently been used for motion biomechanics,[20] postural control,[21] gait measurements (gait speed, stride length, and step time) for fall risk,[22–25] assessment of neck and head position after neck motion,[26] and assessment of head posture.[17–19] However, the validity within a routine clinical setting, along with the effectiveness and accuracy of the system when using Microsoft Kinect, has yet to be definitively established and needs to be compared to the widely used measurement methods currently used in clinics. In 2014, Nakamura et al developed a Kinect-based semi-automatic scoring method (KSSM) for head posture. They suggested that KSSM could be used to track patients' faces and bodies, automatically analyze neck angles and semi-automatically calculate the Toronto Western Spasmodic Torticollis Scale (TWSTRS) severity scale score.[18] In 2019, Nakamura et al compared the TWSTRS severity scale scores calculated by KSSM with the video-based scores calculated by a neurologist trained in movement disorders.[19] The intraclass correlation coefficients [ICC] (3, 1) of these two TWSTRS severity scale scores were 0.617 ($p < 0.001$, 95% confidence interval [CI]: 0.259–0.798), concluding that the KSSM method has sufficient validity and head posture measurement reliability for use within routine clinical practice. In a separate study that was conducted in 2014 at the same time as and independently of the Nakamura et al study, Oh et al developed a digital head posture measurement system (KHT) using the Microsoft Kinect machine. They reported a very strong correlation coefficient of 0.979–0.988 for the X-, Y-, and Z-axes compared to the CROM device.[17] As CROM is the clinically standard tool to measure AHP in ophthalmology,[8] we investigated the accuracy and reliability of the KSSM for measuring head posture that was developed by Nakamura et al and then compared the results with those for CROM.

Materials and Methods

Participants

The study enrolled 10 ophthalmologically healthy adult volunteers (mean age 27.3 ± 5.0 years; two men and eight women) with normal vision and head posture, and all participants had no medical history including strabismus, amblyopia, nystagmus, head trauma, neck disease, systemic bone disease, or other neuromuscular diseases. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Clinical Research Ethics Committee of the Japan Community Health Care Organization Chukyo Hospital (approval No. 2019038). The protocol and data collection for this study complied with local laws. Written informed consent was obtained from all participants. We have obtained individual permission to publish photograph of the subject in the journal.

KSSM

Nakamura et al developed software using the sample code "Face Tracking Basic" in the Kinect for Windows Standard Development Kit (SDK), which detects and tracks human faces captured by Kinect.[17,18,] This program has now been updated to Kinect v2 (Figure 1) with the updated system named KSSM. In brief, this system can collect real-time data based on the angles of the X-axis (chin up/down), Y-axis (face turn), and Z-axis (head tilt) of the head posture by tracking the position of the participant's face. To perform this measurement, 300 samples were obtained at 30 Hz for 10s. Our analysis used default smoothing parameters (correction factor, 0.5; smoothing factor, 0.5; jitter radius: 0.05 m, maximum deviation radius: 0.04 m, future prediction, zero frames). When the abnormal head position is worse, the KSSM cannot recognize the face, and the result is not displayed. If a KSSM result was displayed, it was considered measurable (Table 1 and Figure 1).

CROM®

We used the CROM3 (Performance Attainment Associate, St. Paul, MN, USA), which consists of three indicators: two inclinometers and a compass that responds to a shoulder-mounted magnetic yoke. In this study, the CROM device was fitted on the back of the participant's head to increase accurate face recognition without interference from the front indicator of the CROM device (Figure 2). Except for the above-mentioned fitting, the CROM device was used according to the manufacturer's instructions.

Procedure

The same examiner (M.Y.) performed all procedures that were used to measure the head position of the 10 participants, and they were instructed to sit on a chair and maintain their posture with their backs straight. The distance from the KSSM to the

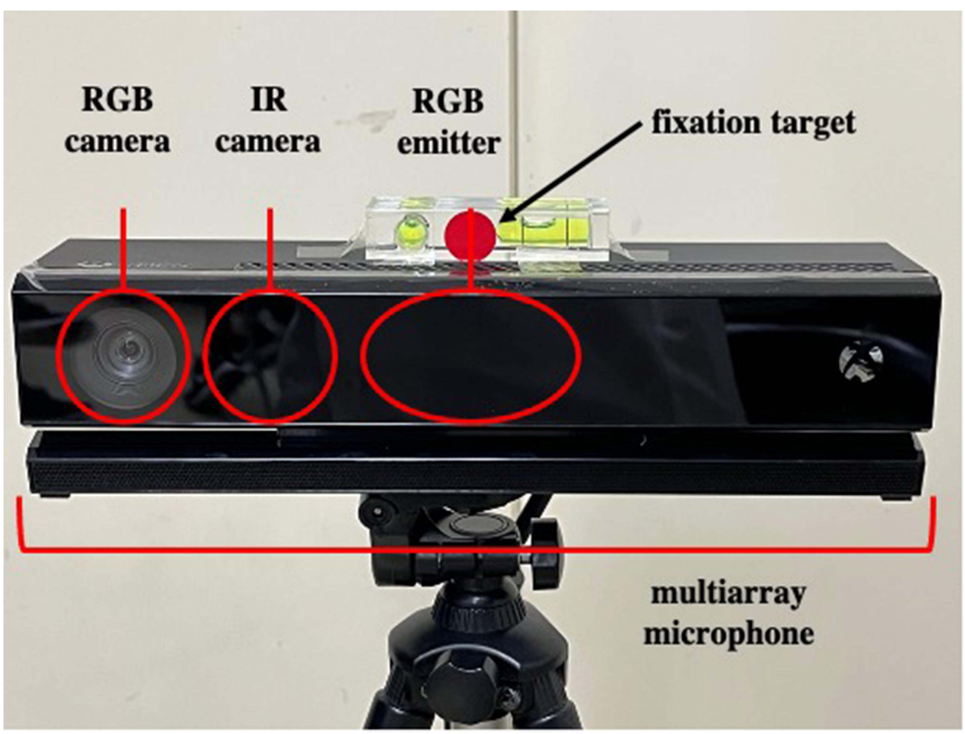

Figure 1 The Kinect v2 sensor bar is shown with an RGB camera, infrared (IR) camera, and IR emitter The black arrow is a fixation target on Kinect v2.

Table 1 Head Position in KSSM for Each Angle of Abnormal Head Position in CROM the Mean ± Standard Deviation of the KSSM When the Face Was Moved by 10° in CROM is Shown

	−40°	−30°	−20°	−10°	10°	20°	30°	40°
X axis	−36.95±2.79	−29.31±1.96	−19.95±3.39	−10.80±2.45	9.98±1.58	19.34±2.58	28.06±2.29	34.94±1.40
Y axis	−38.22±1.34	−30.57±2.92	−20.24±2.43	−12.18±1.32	11.16±2.52	19.47±2.30	30.16±2.58	39.13±1.87
Z axis	−37.01±2.05	−27.42±0.79	−19.10±1.31	−10.83±1.83	10.79±2.06	19.17±2.42	28.66±2.47	38.27±2.50

participant's face was 1 m, and the KSSM sensor was installed at the height of the center of the two eyes of the participant. For the AHP sample, all participants had their head angles measured in nine directions in each axis (X, Y, Z) in 10° increments from −40° to 40° for a total of 25 directions when using the CROM device. When the head position of the CROM device indicator showed an angle of 0°, it was set as the 0° head position for the KSSM device.

The following four points were analyzed in this study: the success rate of each cephalometric measurement by KSSM, the correlation between cephalometric angles measured by KSSM and CROM using Spearman's rank correlation coefficient, the comparison of KSSM and CROM results using 95% limits of agreement [95% LA], and the presence of proportional error for 95% LA by linear regression analysis was used. The results are shown as the 95% CI (GraphPad Prism 8; GraphPad Software, Inc., San Diego, CA).

Results

The success rate of the KSSM for all positions of the X-, Y-, and Z axes that were within ± 30° was 100%. Nevertheless, the measurable rates for the chin-up of 40° and chin-down of 40° were comparatively low (50% and 40%, respectively).

Correlations and 95% LAs in the −30° to 30° range, where the measurability was 100%, were analyzed. The Spearman correlation coefficients for both methods were 0.979 (95% CI: 0.965–0.988), 0.988 (0.980–0.993), and 0.966 (0.944–0.980) for the X, Y, and Z axes, respectively (Figure 3).

The KSSM and CROM results were compared at 95% LA (Figure 4). The mean difference between the two measurements on the X-, Y- and Z-axis was −0.45° (95% LA: −5.54 to 4.65), −0.37° (95% LA: −5.5 to 4.76) and

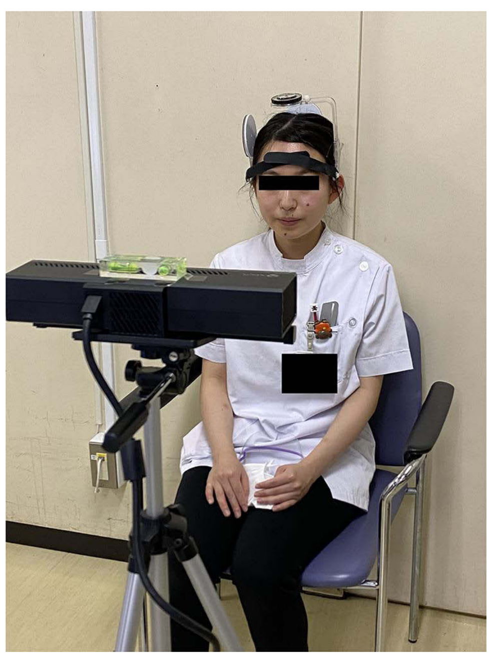

Figure 2 Photograph showing simultaneous measurement of the head posture with KSSM and CROM3 The Kinect v2 was fixed at the participant's eye level while sitting at a distance of 1.0 m from the device. CROM3 was fitted on the back of the participant's heads to increase the accurate face recognition without any interference caused by the front indicator of the CROM3 device. We have obtained individual permission to publish photograph of the subject in the journal.

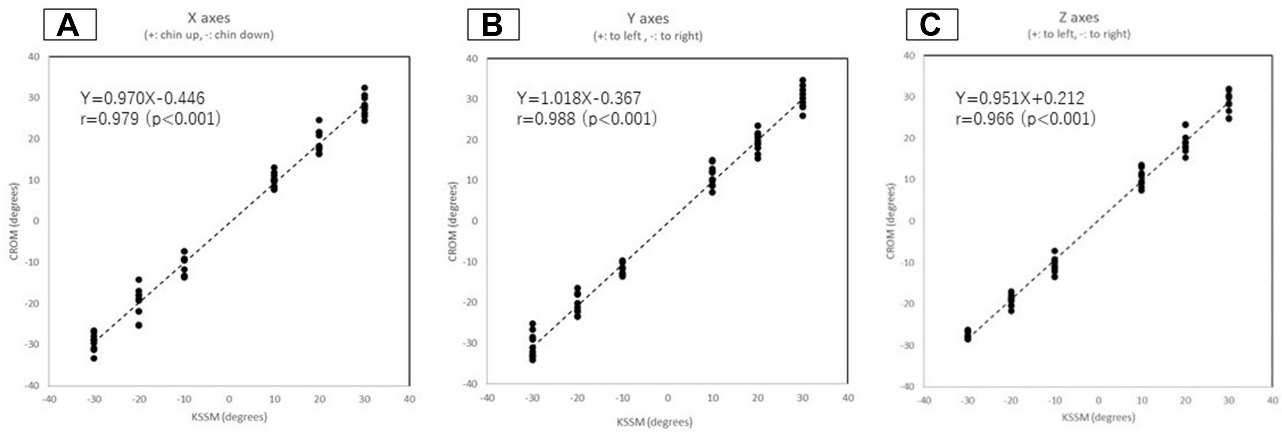

Figure 3 The Spearman correlation coefficients between KSSM and the CROM device for X (**3A**), Y (**3B**), and Z axes (**3C**) A significant correlation was observed for the relationship between the measurements of KSSM and the CROM for all three head movements (chin-up/down: r=0.979 (95% CI: 0.965–0.988), face turn: r=0.988 (95% CI: 0.980–0.993), and head tilt: r=0.966 (95% CI: 0.944–0.980).

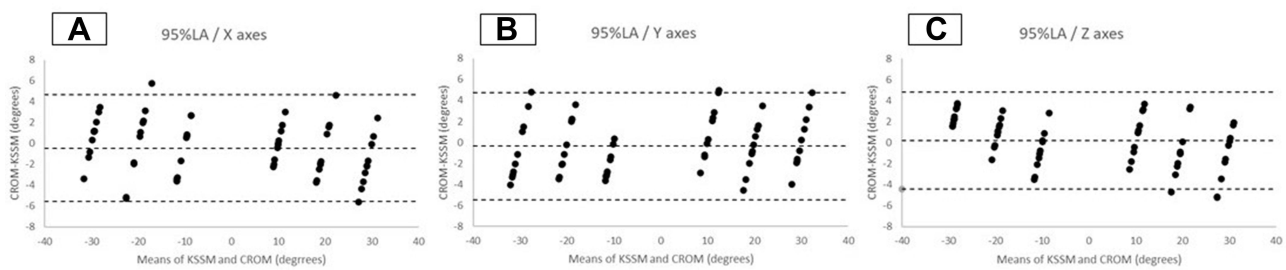

Figure 4 Comparison of the KSSM and CROM results by 95% LA, which indicates the amount of agreement of the means for these two measurements against the difference between two methods for chin-up/down (**A**), face turn (**B**), and head tilt (**C**) Horizontal lines are drawn at the mean difference (solid line) and at the limits of agreement (bold dotted lines), defined as the mean difference plus or minus 1.96 times the standard deviation (SD) of the differences.

0.21° (95% LA: −4.41 to 4.84), respectively, with no statistical difference between CROM and KSSM in either direction no statistical difference was found between CROM and KSSM in any direction ($p = 0.19$, $p = 0.28$, and $p = 0.48$, respectively).

The simple linear regression analysis of the 95% LA determined three equations: $Y = -0.024X - 0.452$ for X-axes, $Y = 0.024X - 0.363$ for Y-axes, and $Y = -0.045X + 0.217$ for Z-axes (95% CI for each: −0.055–0.007, −0.006–0.050, −0.071- −0.018). The 95% LA analysis revealed no proportional bias in either direction. Nevertheless, the predicted value for the difference between the two methods by the equation for the participant's head position angled from −30° to 30° for both directions was within ±2°. These results indicate that the agreement between the two methods for measuring head posture appears to be the same and valid in routine clinical practice.

Discussion

We estimated the accuracy and reliability of the KSSM compared to those of the CROM device. Although this study was conducted in normal adults with AHP, high correlation coefficients were found for all the axes that were compared between the KSSM and CROM (X axes: 0.979 (95% CI: 0.967–0.987), Y axes: 0.985 (95% CI: 0.976–0.991), and Z axes: 0.988 (95% CI: 0.981–0.993)).

In an independent comparison study, Oh et al examined the difference between the CROM device and KHT using the Microsoft Kinect machine, and they reported excellent agreement with the high correlation coefficients for all of the axes (chin up/down: 0.997 ($p < 0.001$), face turn: >0.998 ($p < 0.001$), and head tilt: 0.999 ($p < 0.001$)).[17] KHT or our currently used device can also be recommended as a test method in clinical settings. Oh et al pointed out the following four important requirements for head posture measurement systems to be considered advantageous and that can be easily used in a clinical setting: (1) an ability to obtain instantaneous and reliable measurements of a three-axis head rotation, (2) having a low system price, (3) ease of setting up and initiating measurement, and (4) patient comfort, such as contact-free use.[17] We are particularly in agreement with the fourth point concerning infantile patients.

For all axes, although the measurable rates in this study were 100% within 30° angles of the head position, there was a decrease in the rates for a 40° angle of the head position. There have been few reports regarding the actual ranges of ocular AHP in strabismus clinics. Kushner measured the AHP using CROM in 10 patients and found that the mean amounts for the chin position, face turns, and head tilt were 14.4° ± 10.7° (SD) (−20–38°), 16.5° ± 12.5° (0–39°) and 15.3° ± 13.5° (from 0° to 40°), respectively.[8] Turan et al measured the AHP using orthopedic goniometry in 163 patients and found that the mean degrees for the chin-up position, face turn, and head tilt were 19.22° ± 7.45° (8–35°), 18.92° ± 7.08° (10–45°) and 20.30° ± 9.04° (5–40°), respectively.[5] After taking these degrees of AHP into consideration, we propose that a measurable range within 30° of the head position for all axes when using KSSM will be sufficient and applicable for most of the patients with AHP. However, when using Microsoft Kinect, appropriate visual inputs of the participant's face, including the positions of the eyes and nose, are required to calculate the head posture. When the AHP exceeds 30°, and facial feature points cannot be appropriately captured, then the position of the camera for the KSSM should be shifted 10° from the adjusted center line, and the obtained measurements are corrected to obtain the AHP degrees.

The 95% LA analysis revealed that a statistical linear regression could not be obtained between the differences in frequencies measured by the CROM and KSSM and that there was no proportional bias. However, the actual ocular AHP range in the strabismus clinic was primarily −30° to 30°, and the mean difference in position from −30° to 30° between the two methods calculated using these equations was 0.45°, −0.37°, and 0.21° for X-, Y-, and Z-axis in the two methods, respectively. Based on these analyses, the agreement between the two head posture measurement methods indicates that they can be used in routine clinical settings.

In 2021, Burchell et al reported that the depth camera using Kinect was less accurate at measuring head positions in comparison with the electromagnetic tracking system (Polhemus, Colchester, VT, USA) as a gold standard head position measurement device.[27] They reported that measurements with the two devices were not statistically significantly different for face turning and head tilt from −30° to 30°. However, they found that measuring the chin-up and chin-down head positions was less accurate. A small amount of variability in head position was recorded with the Kinect (1.36–1.53°) and Polhemus devices (0.74–0.99°), and only the 0.75° and smaller statistically significant difference in the stability of the chin down and up head movement between the two devices were found. However, comparing Kinect's agreement limits (−5.30 to +4.98°) with previous reports of good test–retest variability[17] by Oh et al, Kinect is recommended as a depth camera for measuring head position without being attached to the head of an infant patient in an ophthalmology clinical setting.

This study had a limitation. We did not estimate the validity and reliability of the KSSM in patients with AHP. However, Nakamura, who is one of the co-authors in this study, and colleagues compared two TWSTRS severity scale scores that were calculated by the KSSM and by a neurologist trained in movement disorders and found that there was a statistically significant correlation between these two TWSTRS severity scale scores within routine clinical settings.[19] Thus, further examination of the differences observed in head postures in AHP patients when using the KSSM and the CROM device should be conducted in the future to definitively establish the accuracy and reliability of the KSSM evaluation of AHP patients in the ophthalmological field.

In conclusion, the KSSM showed good agreement with the CROM device, with high correlation coefficients. After considering the advantages of the KSSM concerning contact-free operation, high performance, and low cost, this suggests that the KSSM could be clinically used as a quantitative head posture method to measure AHP patients, especially in infants with AHP.

Consent for Publication

This study was conducted in accordance with the Declaration of Helsinki. All data were de-identified, and no personally identifiable information was included in this report.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas, took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no conflicts of interest in this study.

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