Application of a Digital Head-Posture Measuring System in Children

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• PURPOSE: To report the repeatability of a digital head-posture measuring system when used to record anomalous head postures in children.
• DESIGN: Prospective study and clinical laboratory investigation.
• METHODS: Using a digital head-posture measuring system, we measured 36 different anomalous head postures in 27 children with infantile nystagmus syndrome. Repeatability values and 95% limits of repeatability of measurements were generated for anomalous head postures.
• RESULTS: Among the 27 children, 3 had 2 head postures (right and left head turns) in 2 different directions; 6 had 2-dimensional head postures that were considered 2 different head postures; and 18 had a 1-dimensional head posture. There were 5 chin-up or chin-down postures, 23 head-turn postures, and 8 head-tilt postures in a total of 36 anomalous head postures. The repeatability value for all anomalous head postures was less than 10 degrees. Ninety-five percent limits of repeatability yielded ranges of less than 10 degrees for all anomalous head postures.
• CONCLUSIONS: The digital head-posture measuring system is a valid and reliable device for measuring 3-dimensional head postures in children with nystagmus. (Am J Ophthalmol 2010;xx:xxx. © 2010 by Elsevier Inc. All rights reserved.)

ANOMALOUS HEAD POSTURE OR OCULAR TORTICOLLIS is a common clinical symptom in the pediatric population.[1–3] It has been found that up to 62% of children with nystagmus have anomalous head postures.[4] There is evidence that early corrective surgery for children with ocular torticollis improves visual function[5] and may prevent musculoskeletal problems resulting from uncorrected ocular torticollis.[2,3] Thus, an effective technique for accurate measurement of ocular torticollis in children is valuable to assist with evaluation and surgical planning. We have developed a digital head-posture measuring system and have shown it to be sufficiently accurate and to yield repeatable outputs from testing a manually positioned artificial head and cooperative adult subjects.[6] This study examined the repeatability of measurements with the digital head posture system when used with children with ocular torticollis.

METHODS

• PATIENT PROFILE: Twenty-seven children with abnormal head posture and nystagmus participated in the investigation (Table). Our inclusion criteria involved an age range of patients of either sex from 6 months to 13 years. Patients who fell out of the desired age range were excluded from this study. The mean age for the children was 6.2 years (6 females and 21 males). The protocol and testing were approved by the Institutional Review Board of The University of Pittsburgh and conformed to the requirements of the United States Health Insurance Portability and Accountability Act. All procedures observed the Declaration of Helsinki, and informed consent was obtained from all subjects' parent or legal guardians.

• DEVICE: Detailed information regarding the digital head-posture measuring system has been reported[6] and is available in a previously published article. Herein, we briefly describe the digital head-posture measuring system. The digital head-posture measuring system consists of a motion tracker mounted on an adjustable headset, a controller personal computer, and custom software for data recording and visualization. The adjustable headset was modified from prior studies. The plastic headset was replaced by 2 Velcro strips (Velcro Brand Fasteners, Clifton, New Jersey, USA), allowing for improved child comfort and ease of adjustment (Figure 1). The motion tracker is commercially available and uses hybrid techniques, including a magnetometer, accelerometer, and gyroscope made by InterSense (Model 100-ITRAX-0002; InterSense Inc., Billerica, Massachusetts, USA). The software interface was written in C++. The digital head-posture measuring system continuously measures a patient's head posture at a rate of 20 Hz and presents a real-time animation of a head movement on a liquid crystal display along with numerical readings in 3 dimensions (Figure 2). It records and saves

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TABLE. Major Head Postures for Each Individual

Subject No.	Major Head Posture	Mean (degrees)
1	Chin up + left head tilt	11.37 + −14.53
2	Right head turn	40.57
3	Right/left head turn	23.45/−34.02
4	Right head turn	20.64
5	Left head tilt	−19.92
6	Left head turn	−16.33
7	Right head turn + right head tilt	16.11 + 23.55
8	Left head turn	−38.44
9	Right/left head turn	26.13/−22.77
10	Left head turn	−45.90
11	Right head turn	24.25
12	Right/left head turn	11.41/−18.64
13	Chin down + right head turn	−15.45 + 34.12
14	Right head turn	24.73
15	Chin up + left head tilt	14.04 + −22.12
16	Left head turn	−23.89
17	Chin down	−16.37
18	Left head tilt	−15.07
19	Left head turn	−23.87
20	Left head tilt	−20.67
21	Left head tilt	−12.58
22	Chin down + right head turn	−19.68 + 19.71
23	Left head turn + left head tilt	−28.02 + −13.32
24	Left head turn	−34.60
25	Left head turn	−17.05
26	Left head turn	−25.13
27	Left head turn	−16.23

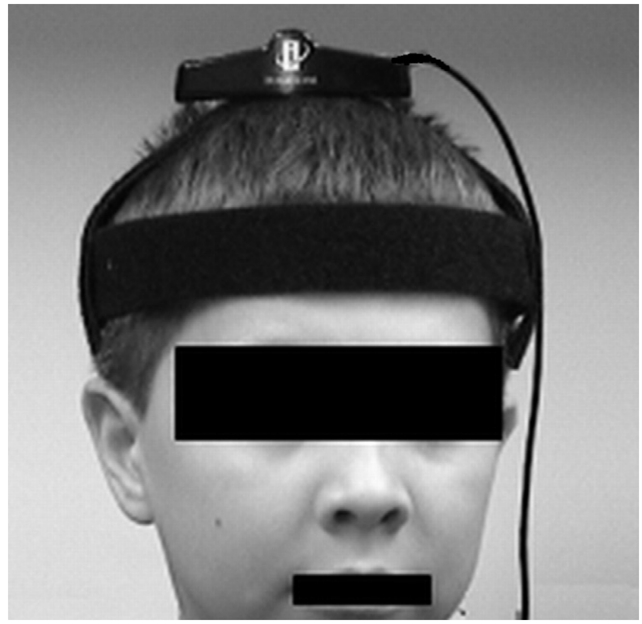

FIGURE 1. **Photograph showing the modified digital head posture measuring device with 2 Velcro strips (Velcro Brand Fasteners, Clifton, New Jersey, USA) and a motion tracker mounted on a child's head. The black cord leads to a USB connection that is inserted into the computer used to record subject head postures.**

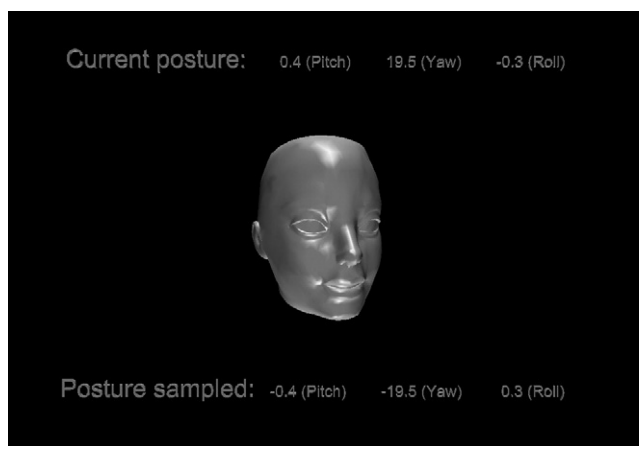

FIGURE 2. **Screen shot of digital head posture measuring device's display of simulated head movements and numerical outputs. Current posture values change in real time, and posture can be sampled and recorded at any time by the user. The abnormal head posture depicted has a chin up of 0.4 degrees, head turn of 19.5 degrees to the right, and head tilt of 0.3 degrees to the left.**

the data into a .txt file for off-line analysis. The saved data include the initial head position, ending head position, and the difference between the 2 positions (head posture in degrees). The manufacturer claims that the tracker works with a full 3600-degree range with angular accuracies of 0.25 degree for chin-up or chin-down and head-tilt measurements and of 0.50 degree for head-turn measurements.

• PROCEDURES: We use the terms *head turn* for rotation around the longitudinal axis (y-axis), *chin up* or *chin down* for rotation around the interaural axis (x-axis), and *head tilt* for rotation around the naso-occipital axis (z-axis) of the head throughout the article. Subjects were seated in an examination chair, and an image was displayed on a screen for the subjects to focus on. Images used were either a letter for older children or a cartoon character for younger children. The distance from the screen to the center of subjects' head was approximately 1.5 m. As soon as a subject reached his or her null position and maintained a steady head posture, the digital head-posture measuring device was zeroed by pressing the space bar on the keyboard by a computer operator. The subject's head then was moved manually by the investigator to actual 0 position (0 degrees for chin up or chin down, head turn, and head tilt) by a clinician using a head-rest frame behind the subjects as a reference. As soon as the true 0 position was reached, the enter button was pushed to freeze the instantaneous 3-dimensional angles for the subject's abnormal head posture. The clinician did not obtain any instantaneous results. A total of 5 measurements were obtained for each head posture.

• DATA ANALYSIS: Of the 5 measurements recorded for each head posture, the maximum and minimum values were removed, yielding 3 sets of 3-dimensional data. This was mainly because a large variation of head posture in children frequently was seen, and excluding the maximum and minimum values produced more reliable data for clinical application. The remaining data were analyzed to determine repeatability values, *r*, for every dimension. The equation for repeatability is shown below[7]:

$$r = 2.77 \times \text{SD} \qquad [1]$$

where SD is the standard deviation determined by finding the square root of the within group mean squares as determined by a 1-way analysis of variance.

We first plotted standard deviations of the measurements against their means to determine if there is any bias involved regarding standard deviations and the magnitude of measurements.[8,9] Repeatability was analyzed using 95% limits of agreement between any 2 of the 3 tests using the following equation from Bland-Altman method[10]:

$$\text{95\% Limit of Agreement} = \text{Mean} \pm 1.96 \times \text{SD of Differences} \qquad [2]$$

The values of 95% limit of agreement between test 1 and test 2, test 2 and test 3, and test 1 and test 3 were calculated.

RESULTS

ALL 27 SUBJECTS SUCCESSFULLY COMPLETED MEASUREMENTS of their anomalous head postures. Among the 27 subjects, 3 had 2 head postures (right and left head turns) in 2 different directions. Six had 2-dimensional head postures that were considered 2 different head postures. Eighteen had 1-dimensional head postures. A summary of subjects and their 36 major head postures is shown in the Table. As demonstrated in Figure 3, no clear bias is shown and most values of standard deviations are less than 5 degrees.

Repeatability values, *r*, for all anomalous head postures were calculated using the method described in Equation 1. Repeatability values for chin up or chin down, head turn, and head tilt postures were found to be 5.92, 9.20, and 6.94 degrees, respectively. An overall repeatability value for head postures for all 3 dimensions was found to be 8.36 degrees.

Ninety-five percent limits of repeatability also were computed between the 3 independent sets of data for all head postures measured. Bland-Altman analysis of difference versus mean between any 2 sets for all 3-dimensional movements was performed to obtain these limits of repeatability. Mean difference and mean ± 95% limit of agreement lines were created using Equation 2. Five chin-up or chin-down head postures were recorded, and their magnitudes ranged from 9.5 to 21.3 degrees, with an average of approximately 15.4 degrees. The 95% limits of repeatability were found to be approximately ± 5.5 degrees for chin-up or chin-down postures between trials 1 and 2, ± 4.5 degrees between trials 2 and 3, and ± 8.0 degrees between trials 1 and 3. Twenty-three head-turn postures were obtained, and their magnitudes ranged from 6.2 to 48.8 degrees, with an average of 25.5 degrees. The 95% limits of repeatability were found to be approximately ± 6.7 degrees for head-turn postures between trials 1 and 2, ± 10.0 degrees between trials 2 and 3, and ± 10.0 degrees between trials 1 and 3. Eight head-tilt postures were measured, and their magnitudes ranged from 10.7 to 27.4 degrees, with an average of approximately 17.9 degrees. The 95% limits of repeatability were found to be less than ± 7.5 degrees for head-tilt postures between trials 1 and 2, ± 6.3 degrees between trials 2 and 3, and ± 6.5 between trials 1 and 3.

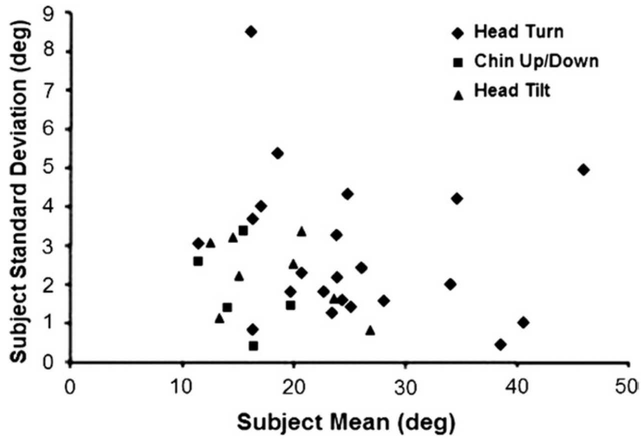

FIGURE 3. Scatterplot showing subject standard deviation against subject mean of 3 measurements of all head postures. The repeatability values are 5.92 degrees (deg), 9.20 deg, and 6.94 deg for chin-up or chin-down, head turn, and head tilt measurements, respectively.

DISCUSSION

IN PAST CLINICAL PRACTICE, SOME CLINICIANS DETERmined the magnitude of anomalous head posture through simple observation. Such observations have been shown to have an error from 2 to 18 degrees in visual estimation.[11] Research has shown increasing errors with simple observation methods for those with more severe anomalous head postures. For example, a 30-degree head turn resulted in examiner estimates varying from 10 to 50 degrees.[12] These kinds of clinical errors could adversely affect the planning and outcome of treatment. Several methods have been developed to measure anomalous head postures, including more accurately, including a cervical range of motion device[13] and photographic[14,15] and mechanical[16] methods. Unfortunately, these methods require time-consuming analysis and a fair amount of cooperation, making them difficult for applications in pediatric population.

Having previously shown the intrinsic accuracy of the digital head-posture measuring system,[6] we decided to focus only on the repeatability of trials involving children and development of a consistent and suitable method for making clinical measurements. We found that the digital head-posture measuring system could measure the anomalous head posture in children reliably. Advantages of the system are that it instantaneously generates 3-dimensional results and that it eliminates human error involved in manual recording of measurements.

Repeatability values from multitrial measurements of the 36 anomalous head postures were found to be less than 10 degrees for all chin-up or chin-down, head turn, and head tilts. This means that 95% of head posture measurement pairs will have a difference of less than 10 degrees. We believe this is within a clinically acceptable range of repeatability. In addition, the 95% limits of agreement of the device agreed with the repeatability values found. The 95% limits of agreement were less than ± 10 degrees for all dimensions. Compared with the visually estimated variation of 10 to 50 degrees for an abnormal head posture of 30 degrees,[15] these values are noticeably better. The 95% limits of agreement for normal adult subjects were found to be ± 4.0 degrees, ± 4.0 degrees, and ± 8.0 degrees for chin up or chin down, head turn, and head tilt, respectively, which were slightly better or similar to the results from children.[6]

The digital head posture method is quick and easy, with each measurement taking only a few seconds. Additionally, multiple tests can be completed and recorded within a matter of minutes, capitalizing on the limited attention spans common in children.

Although our device shows great promise in being an acceptable method for measuring the head posture of young patients, it does have some limitations. First, the device drifted over time. If we allow enough time for a child to demonstrate his or her head posture, sometimes the outputs of the device showed inaccurate values. To avoid the problem, we allowed our patients show their head posture first and set the abnormal head posture to 0, and then moved the patient's head back to the normal head position. Our measurements were improved by using this reversal strategy. Second, large variation of head posture in children frequently was seen because of the natural variability of abnormal head posture in pediatric patients. To provide reliable head posture data for clinical application, such as surgery design, we chose to obtain multiple measurements and to remove the highest and lowest values of these measurements. However, removing the highest and lowest values of these 5 measurements reduced the variability of the device's output. Thus, we suggest using this as the actual protocol when using the device. The repeatability values reported reflect the repeatability of the 3 measurements retained using our measurement protocol and are not valid unless our specific measurement protocol of removing the highest and lowest values of 5 measurements is used. Also, the natural variability of abnormal head postures in child patients contributes to the repeatability of the measurements. Third, the device needs a regular personal computer, which may be expensive. Finally, our current study does not evaluate the accuracy of the device when used with children, but it has been shown to be accurate when compared with a mechanical head posture-measuring device used on an artificial head and with normal adult subjects.[6] Considering the resulting repeatability of the digital head-posture measuring system when used in children along with previous data showing it to have high accuracy in adult subjects,[6] we believe the system is a valid and reliable device for measuring abnormal head posture in pediatric patients.

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Biosketch

Eric S. Hald is a first year graduate student in the PhD biomedical engineering program at the University of Minnesota-Twin Cities, Minnesota. He has been a research assistant in the past at the Laboratory of Ocular Motor Research in Children's Hospital of Pittsburgh, under the direction of Drs. Dongsheng Yang and Richard Hertle. He has presented posters at the AAPOS 2007 and ARVO 2008 conferences, detailing his various stages of work with a digital head posture measuring device. He received Fight-For-Sight's Summer Research Fellowship grant for Summer 2008 to continue his research in developing a head posture measuring device. His career interests include research in the field of tissue engineering and biomechanics.

Biosketch

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