EVALUATION OF THE WRISTCORDER™: A HAND-FOREARM MOTION ANALYZER

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For effective control and assessment of harmful hand-forearm motion at work, a valid goniometric system that produces reliable and accurate measurements is essential. The present study evaluated the WristCorder™, a portable motion analyzer for flexion/extension (F/E), ulnar/radial deviation (U/R), and pronation/supination (P/S) of the hand-forearm, in terms of linearity, sensitivity, and reliability using the Triaxial Hand-Forearm Fixture. Eight participants having no history of musculoskeletal disorders were recruited for the evaluation. The motion analyzer produced sensor values linearly related to angular movements of the limb; sensitivity was less than 1° for F/E and U/R and between 2.5° and 3.5° for P/S; standard deviation due to measurement error was about 1° for F/E and U/R and about 2.4° for P/S; and standard error of measurement was less than 1° for F/E and U/R and 2.3° for P/S. The motion analyzer may be used as an effective tool to analyze unidimensional movements of the hand-forearm in industry. Continued study is needed to generalize the evaluation results in three-dimensional motion analysis.

INTRODUCTION

Improper motions of the hand and forearm such as hyper-deviated postures of the wrist from the neutral position and rapid twisting motions of the forearm have been identified as a major risk factor of upper extremity musculoskeletal disorders (UE-MSDs). For effective assessment and control of these harmful motions at work, an instrument that can accurately and reliably measure hand-forearm motions has been needed. A valid hand-forearm motion system should be able to analyze and assess physical activities in multiplanar and dynamic environments so that the analyst can effectively develop control measures to prevent workers from UE-MSDs.

The WristCorder™ (Figure 1), developed by the MotionWatch LLC, is an instrument that can measure and analyze motions of the hand-forearm in three dimensions: wrist flexion/extension (F/E), ulnar/radial deviations (U/R), and forearm pronation/supination (P/S). The motion analyzer consists of a glove with three Hall-effect sensors to measure movements along corresponding dimensions, a portable data storage unit, and analysis software. Each sensor houses one end of a rod with a magnet, of which the other end is attached to a designated site on the glove; the sensor produces an output voltage proportional to the extent of movement of the magnet rod. The small, light recording device attached to the glove stores voltage readings with a sampling rate of 10 Hz for 8 hours. The data can be downloaded to a computer and displayed in histogram form broken into ranges of the defined angle and tallied in terms of the amount of time in each range.

Figure 1. WristCorder™ hand-forearm motion analyzer

The objectives of the present study were to evaluate the linearity, sensitivity, and reliability of the WristCorder™. To evaluate the hand-forearm measuring instrument along three axes in a laboratory setting, this study developed the Triaxial Hand-Forearm Fixture and a testing protocol.

MATERIALS AND METHODS

Participants

Eight participants (four participants for each glove size) were selected based on hand circumference at the metacarpals and forearm circumference (relaxed) corresponding to two sizes of WristCorder™ gloves: 16.1 to 17.4 cm for medium and 19.1 to 22.4 cm for large for hand circumference; 19.6 to 25.0 cm for medium and 22.0 to 31.0 cm for large for forearm circumference. Participants reported no history of hand, wrist, or forearm injuries and were 18 years of age or older. They received a description of the experiment and gave informed consent. Their participation was compensated.

Apparatus

The WristCorder™ and Triaxial Hand-Forearm Fixture (Figure 2) were used in the evaluation. Participants wore a right-handed WristCorder™ glove equipped with three linear Hall-effect sensors to measure F/E, U/R, and P/S. The fixture consists of three main sections: (1) forearm section having supports for the ventral and medial sides of the forearm, a jack, a ball-joint, and a control bar for the elbow; (2) hand support section including a ring for the distal tip of the middle finger and a strap across the proximal phalanges; and (3) angle control section having a metal coupling, dowel pins, and angle templates.

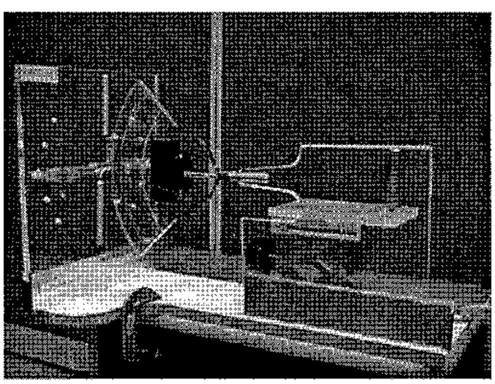

Figure 2. Triaxial Hand-Forearm Fixture

Design of Experiment

Uniplanar movements were measured along each of the three dimensions. For each dimension, counterbalanced across the participants, the hand-forearm was locked at five different positions (F/E: F40°, F20°, neutral, E20°, and E40°; U/R: U30°, U20°, U10°, neutral, and R10°; P/S: P40°, P20°, neutral, S20°, and S40°) with three repetitions presented in randomized order. Each participant received 45 trials.

Procedure

The WristCorder™ was placed on the participant's right hand and forearm using two points, the third metacarpal and the dorsal center of the wrist, to align the F/E sensor on the glove. The midline of the forearm was marked with a tape strip on the ventral side of the glove using the third metacarpal and the center of the ventral side of the wrist to determine the neutral position for the hand and forearm. The ventral wrist center was marked with a circular marker.

Participants were seated in a chair adjusted at the elbow height (sitting) so the medial side of the forearm properly rested on the related support for the forearm in the fixture. The midline marker on the glove was aligned to a reference line on the template for consistent placement of the forearm. The control bar was positioned next to the lateral epicondyle of the elbow. The fingers were restrained to the hand support by the strap and the participants were told to keep their thumb next to their fingers. The control bar, midline markers, finger strap, ring, and thumb positioning were used to control for extraneous movement of the hand, wrist, forearm, and elbow.

The experimenter asked the participant to relax their hand and forearm while positioning the angle templates at a specific angle. Participants were asked to hold their position for three seconds by focusing on the circle marker during measurement. At the end of the experiment, participants recorded comments, including any discomfort experienced with the WristCorder™ and fixture. The study protocol was approved by the IRB of the organization.

RESULTS

Linearity/Sensitivity

The linearity between Hall-effect sensor values and angular values and the sensitivity of each of the three sensors were analyzed by regression for each movement direction. The results indicated that the sensor and angle values have strong linear relationship across all the movement directions ($p < .001$; R^2 values: 0.80 – 0.99 for F/E; 0.93 – 0.99 for U/R; and 0.85 – 0.99 for P/S).

Analysis of variance (ANOVAs) on the slopes of the regression lines was conducted for *subject* and *movement direction* for each of the three dimensions (Table 1). The results indicated that the sensitivity of the F/E and P/S sensors varied significantly depending upon movement direction, while that of the U/R sensor varied across the subjects ($p < .1$). The sensitivity values were 0.52° for flexion, 0.38° for extension, 0.91° for ulnar deviation, 0.61° for radial deviation, 2.44° for pronation, and 3.26° for supination.

Table 1. ANOVA for slopes of regression line

(a) Flexion/Extension

Source	SS	DF	MS	*F*
Subject	3.87	7	0.55	1.78
Movement Direction	1.62	1	1.62	5.22†
Error	2.17	7	0.31	
Total	7.66	15		

(b) Ulnar/Radial Deviation

Source	SS	DF	MS	*F*
Subject	3.50	7	0.50	3.28†
Movement Direction	0.40	1	0.40	2.61
Error	1.07	7	0.15	
Total	4.97	15		

(c) Pronation/Supination

Source	SS	DF	MS	*F*
Subject	11.80×10^{-2}	7	1.69×10^{-2}	3.07
Movement Direction	1.66×10^{-2}	1	1.66×10^{-2}	3.02†
Error	3.85×10^{-2}	7	0.55×10^{-2}	
Total	17.31×10^{-2}	15		

† $p < .10$; ‡ $p < .05$

Reliability

Analysis of variance (ANOVAs) on sensor values was conducted for *subject*, *angle*, and *repetition* for each dimension (Table 2). The sensor values significantly varied according to subject and angle ($p < 0.001$), but were consistent across the three repetitions ($p > 0.45$). Additionally, standard deviation due to measurement error (SD_{meas}, intrasubject variability) and standard error of measurement ($SE_{meas} = SD_x \times \sqrt{1-r}$; SD_x = intersubject variability; r = Pearson product correlation coefficient between repetitions) were calculated for each dimension (Norkin & White, 1995). Examination of the SD_{meas} and SE_{meas} values indicated that the reliability of the WristCorder™ was high (SD_{meas}: 1.06° for F/E, 0.84° for U/R, and 2.39° for P/S; and SE_{meas}: 0.89° for F/E, 0.83° for U/R, and 2.25° for P/S).

Table 2. ANOVA for measurements

(a) Flexion/Extension

Source	SS	DF	MS	*F*
Subject	6770	7	967	3.2‡
Angle (A)	593920	4	148480	7028.4‡
Repetition (R)	23	2	12	0.6
A × R	155	8	19	0.1
Error	27837	93	299	
Total	628705	114		

(b) Ulnar/Radial Deviation

Source	SS	DF	MS	*F*
Subject	4993	7	713	8‡
Angle (A)	58511	4	14628	25256‡
Repetition (R)	1	2	0.5	0.8
A × R	5	8	0.6	<0.01
Error	9294	98	95	
Total	72804	119		

(c) Pronation/Supination

Source	SS	DF	MS	*F*
Subject	36240	7	5177	405.7‡
Angle (A)	14457	4	3614	657.8‡
Repetition (R)	1	2	0.5	0.1
A × R	44	8	5	0.4
Error	1212	95	13	
Total		116		

† $p < .05$; ‡ $p < .01$

DISCUSSION

A valid goniometric system should provide accurate and reliable measurements for static and/or dynamic movements. A variety of specialized goniometers such as the Ortho Ranger™ (Greene & Wolf, 1989) and DataGlove™ (Wise et al., 1990) have been designed for specific joints and tested for reliability under static postures against the universal goniometer (UG), considered the 'gold standard' for goniometric research. These test results show that the UG is the most reliable measure of static joint motion (see also Petherick et al., 1988) and reliability of measurement depends on the joint being measured with the wrist measurement having the least reliability (range of correlation coefficient = .76 to .94) (Boone et al., 1978; Greene & Wolf, 1989; LaStayo & Wheeler, 1994). However, the UG cannot effectively measure dynamic movements in work settings.

Alternative techniques and instruments for measuring dynamic movements have been developed and used such as video filming, photography, visual observation, Flock of Birds™, Greenleaf WristSystem™, and Cyberglove™. In the video filming and photography techniques, dynamic postures are analyzed by measuring a series of sampled static movements. However, the techniques are time consuming and may increase measurement errors due to parallax. Visual observation involves a subjective judgment of joint movement, which also increases potential for error. These alternative techniques result in low reliability and decreased accuracy of measurement. Lastly, the specialized instruments can record joint motion data in an efficient manner using digital technology, but may interfere with or alter body motion. Furthermore, the two gloves only measure motion about the wrist (i.e., F/E and U/R) and do not measure forearm rotation (i.e., P/S).

The present evaluation demonstrated that the WristCorder™ has stable linearity, satisfactory sensitivity, and high reliability in uniplanar, static movement evaluation. Use of different slopes depending on movement direction and subject is recommended to more accurately convert sensor values to angle values. Sensitivity for the F/E sensor was higher than those for the U/R, with the P/S resulting in the least sensitivity in measurement. The decreased sensitivity of the P/S sensor is the result of less displacement of the corresponding rod during motion as compared with the rod displacements of the other two dimensions. Finally, sensor readings produced by the motion analyzer were reliable across all dimensions within the angle ranges tested.

The results of this evaluation should only be generalized within the tested angle ranges and only for uniplanar motion analysis. Joint movements of the hand and forearm beyond the tested range are, however, uncommon in the work environment; and thus, industry may not need accurate values in the hyper-angle motion range. The present study tested the WristCorder™ in each dimension separately. Since most work involves three-dimensional movements, the performance of the motion analyzer needs to be evaluated in 3D. Moreover, for scientific research, accurate and reliable measurements are of prerequisite over an entire range of the joint motion. Continued investigation is needed to evaluate the validity of the motion analyzer beyond the tested range.

CONCLUSIONS

The present study evaluated WristCorder™ using the Triaxial Hand-Forearm Fixture and a testing protocol for uniplanar and static movements. Use of the fixture and protocol enabled the consistent positioning of the hand-forearm at a designated angle. The Hall-effect sensors of the motion analyzer produced a strong linear relationship with the hand-forearm movements within the tested angle range. Sensitivity of the F/E and U/R sensors was less than 1° and that of the P/S ranged from 2.5° to 3.5°. Standard deviation due to measurement error was about 1° for the F/E and U/R measurements and about 2.4° for the P/S. Lastly, standard error of a single measurement was less than 1° for the F/E and U/R and 2.3° for the P/S. Further study of the motion analyzer is needed to generalize the evaluation results beyond the tested ranges and in three-dimensional motion analysis.

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REFERENCES

Boone, D.C., Azen, S.P., Lin, C., Spence, C., Baron, C., and Lee, L. (1978). Reliability of goniometric measurements. *Physical Therapy, 58*(11), 1355-1360.

Greene, B.L., and Wolf, S.L. (1989). Upper extremity joint movement: comparison of two measurement devices. *Archives of Physical Medicine and Rehabilitation, 70*, 288-290.

LaStayo, P.C., and Wheeler, D.L. (1994). Reliability of passive wrist flexion and extension goniometric measurements: A multicenter study. *Physical Therapy, 74*(2), 162-176.

Norkin, C.C., and White, D.J. (1995). *Measurement of Joint Motion: A Guide to Goniometry.* Philadelphia, PA: F.A. Davis Co.

Petherick, M., Rheault, W., Kimble, S., Lechner, C., and Senear, V. (1988). Concurrent validity and intertester reliability of universal and fluid-based goniometers for active elbow range of motion. *Physical Therapy, 68*(6), 966-969.

Wise, S., Gardner, W., Sabelman, E., Valainis, E., Wong, Y., Glass, K., Drace, J., and Rosen, J.M. (1990) Evaluation of a fiber optic glove for semi-automated goniometric measurements. *Journal of Rehabilitation Research and Development, 27*(4), 411-424.