Advances in Physics Theories and Applications
ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol 4, 2012

Man and Machine? The Measurement of Range of Movement of the Wrist

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Abstract
This paper documents a pilot study undertaken to compare the effectiveness and efficiency of manually measuring the range of movement at the wrist using both a traditional goniometer and a motion capture technique (using a CODA system). Fifteen subjects, male and female 18-22 years old were measured using both techniques. The results indicate a variation of adduction and abduction values at the wrist, beyond that stated in existing references. The manual goniometric data collection was quicker than using the CODA system. A longer time period was spent in preparation and post processing of the result from the CODA system into a spreadsheet. However, the CODA system provided a more detailed description of the ROM of a wrist, highlighting the compound angle made by the wrist during the measurement of adduction and abduction which is not shown through manual goniometry.
Keywords: ergonomics, man, machine, wrist, effectiveness.

1. Introduction

It has been established that position of forearm, wrist and hand during manual handling or manipulative tasks can affect an individual's ability to grip an object (Pryce, 1980). However, the authors do not know of any work being undertaken to investigate the relationship between wrist mobility and an individual's ability to perform a manual handling task. This investigation is part of a programme of work to define the characteristics and performance of the hands using a sample of the Nigeria population, sponsored by the Nigeria Population Commission.

The tests documented within this paper describe the use of two methods of goniometric measurement, conventional goniometric measurement by an operator using a goniometric, and the angular measurement taken using a motion capture machine. The aim of this trial was to review the effectiveness and efficiency of the motion capture machine, Cartesian Optoelectronic Dynamic Anthropometer (CODA), in recording Range of Motion (ROM) at the wrist, against manual measurement of the same angles. It was also to identify any relationships between conventional measurements of hand characterizes anthropometrics and grip strength. The evaluation of how appreciate is it to use a motion capture system to record anthropometric characteristics of a subject within a trial is also discussed.

Measurements were taken from a population of 157 first year undergraduate students, (of which 76 were female), from the department of Materials and Production Engineering, Ambrose Alli University and the Department of Industrial and Production Engineering, University of Ibadan. They were aged between eighteen and twenty-two years, old. No student had any impairment or abnormality in his or her hands. The trial ran between January and June 2011.

2. Method

The subjects were invited to take part in the trial which was undertaken in two phases, measurement of anthropometric data, followed by measurement of other aspects of hand performance such as grip strength, finger compliance and finger friction, detailed in previous references (Torrens and Gyi, 1999). The series of measurements to be taken were discussed with subjects and their writer approval given before taking part in the trial. All measurements to be taken were discussed with subjects and their written approval given before taking part in the trial. All measurements were taken in a room with ambient temperature, humidity and away from direct sunlight. In phase one; anthropometric measurements were taken from all 157 subjects. The measurements taken were of the right hand only, for speed of measurements, and the subject's dominant hand recorded. BS 7231 (1990) was used as a guide to method of anthropometric measurement.

In phase two, grip strength, finger friction, finger compliance and ROM measurements were taken from

thirty-five subjects, fourteen of whom were female. Finger friction and compliance were also measured but are not discussed in this paper. Thirty-five subject from the sample population had the ROM of their wrists measured and were chosen to be reprehensive of the anthropometric percentile range of the population. Two operators processed subjects in groups of five. Due to time constraints, each measurement was taken only once, manual and machine measurements were taken in the same order each time and by the same operator. A consultant ergonomist who was experienced in taking anthropometric measurements was one of the operators. Data was recorded by hand. The finger friction and compliance measurements required a rest period of at least five minutes between each measurement and so the wrist goniometric (ROM) measurements were done between each finger test. Grip strength measurement followed the protocol described by Mathiowetz et al, 1994 and Torrens and Gyi, 1999.

ROM of the hand about the wrist was measured using a modified conventional clinical joint motion protocol (Rowe *et al*, 1965). The flexion and extension of the hand about the wrist were measured with the hand in a mid-supinated (or neutral) position, i.e. at 90^0 to the horizontal. The authors were aware this would make the comparison of collected data with existing ROM references difficult, but would not affect the validity of the comparison between manual and machine measurement of the same subject. The chair in which the subject sat was fixed to avoid the need to adjust the CODA field of view for each new subject. It was necessary to constrain the limb position. A single CODA system was used and so the positioning of the arm in relation to the field of view of the CODA scanner was critical to ensure all the markers remained in the field of view.

Each subject sat upright in a conventional steel contract chair, (seat height 400mm), with their right forearm held at a right angle, horizontal to the floor. The subject was shown the sequence of hand movements required. These were flexion (into the body), extension (away from the body), adduction (upward), and adduction (downward). All hand movements were performed with the subject keeping their arm resting on the goniometer. The operator asked each subject to hold their maximum comfortable hand movement in each direction whilst they took the measurement from the back of the hand, (for flexion/extension), and the axis of the forearm through the centre of the wrist to the envisaged line running through the centre of the third digit (middle finger) for adduction/abduction.

Motion capture measurements were taken using a CODA mpx30. This system uses infrared emitters (markers) attached to the body, via surgical double-sided tape, and stereo sensors within a scanner unit to define an anatomical location on the body. Each subject was fitted with five markers to locate the anatomical references of the hummers (marker one) at its proximal point, ulnar (marker two) and radial (marker three), next to the wrist processes. The proximal side of the metacarpophanangeal joints of the second (marker four) and fifth digits (marker five) were also marked.

With the markers in position, the subject was asked to follow the sequence of movements previously shown to them. The CODA system had been set to sample at 200Hz over a ten second period. Earlier pre-trial tests had shown that this was a sufficient amount of time within which the movements could be completed.

The goniometric data from each motion capture was reviewed and the maximum angles taken from a graph generated by the CODA system software that enables windows-based views. The data was manually transferred on to a spreadsheet following completion of the trial. Only complete sets of data were processed in full. The data sets within the completed spreadsheet were compared through correlation. Analysis and descriptive statistics. Correlation analysis was used to help identify where the measurements taken manually and by machine were comparable. This form of comparison also highlighted the interrelationships between each measurement for further evaluation. Due to the small number of subjects, no further evaluation was undertaken on the data.

3. Results and discussion

Once processed, fifteen complete sets of data from nine males and six females provided the basis for correlation analysis. The lost data was due to operator and compute error. The data gathered from subjects documented in Table1. Shows the statues of the subjects ranged from 1922mm (subject 4, males) to 1522mm (Subject 11, female). The final sample group was not fully representative of largest percentile stature in the original sample population, but did include the smallest female percentile. Weight ranged from 87.7Kgs (Subject 8, male) to 51.5Kgs (Subject 11, female). These results correspond to equivalent

existing data sets for a Nigeria population accessed using the computer-based anthropometric database PEOPLESIZE (Open Ergonomics, 1999). Grip strength ranged from 58Kgs/569N (Subject 2, male) to 23Kgs/226N (Subject 15, female). There were strong correlations between stature and limb length segments.

The ROM results, shown in Table 2, highlighted discrepancies between adduction and abduction values and those published (Rowe *et al*, 1965). Whilst reviewing the motion capture flies, through the CODA software, it was noted that subjects did not hold their wrists vertically during the motion performance and that the angle made between the forearm, wrist and hand was a compound angle even when the hand appeared to be in line with the forearm. A reason for the high abduction value of the female subject 11, shown in Table 2, may be seen in the motion recording. Analysis of her wrist using a graph plot and stick-figure diagram showed that he wrist had rotated over 36% to the vertical, giving the motion a component of extension rather than adduction alone. There were strong negative correlations between abduction and anthropometric values in female group that was not significant in the male correlations within the male group.

4. Conclusion

Following the completion of this study the authors and Chamwood Dynamics Limited have each developed methods to avoid laborious location of makers on to anatomical references on a subject that should significantly reduce preparation time and increase repeatability. The authors are experimenting with a glove with makers attached, Chamwood Dynamics Limited have developed a software solution where the makers are grouped to define body segments. Manual goniometric measurement of wrist motion seems the most cost-effective method of data collection, however, using the CODA system has highlighted a number of issues such as reducing the compound angle between hand, wrist and forearm during measurement when using a manual goniometric. Taking multiple measurements of the whole upper limb at same time would greatly reduce the overall time taken when compared with undertaking the individual goniometric measurements manually. The relationships between measured hand characteristics highlighted in this pilot warrant further study.

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Table 1. Weight and Anthropometric measurements in millimeters of fifteen subjects (1-9 male, 10-15 female)

No	Age	Height	Weight Kg	Grip Kg	Finger tip length	Finger Armtip wrist	Hand breadth	Finger tip length	Finger tip width	Finger Tip depth
1	19	1796	66.5	48	495	197	100	25.9	17.1	13.8
2	19	1858	84	58	454	176	73	30.08	18.11	14.87
3	19	1787	77.5	52	459	188	98	26.96	17.34	14.76
4	19	1922	81	50	537	219	108	31.48	19.3	15.28
5	18	1758	81	37	467	191	96	26.32	18.04	14.73
6	19	1731	76	47	468	191	90	26.58	18.35	15.89
7	18	1630	66.5	42	446	180	96	24.5	16.67	14.12
8	20	1823	87.5	46	524	209	97	29.49	17.97	14.57
9	19	1705	62.5	39	462	188	96	26.07	16.85	14.08
10	18	1752	87	45	481	193	94	39.23	16.86	13.7
11	18	1522	51.5	29	406	155	69	23.73	14.86	12.56
12	18	1663	84	24	468	186	92	23.49	15.76	13.38
13	19	1645	61.5	25	420	170	80	24.71	16.45	13.06
14	19	1674	56	25	428	164	56	26.19	15.65	12.65
15	19	1621	59	23	389	147	53	24.57	14.76	12.61

Table 2. Goniometric measurements, in degrees of fifteen subjects (1-9 male, 10-5 female)

No	Flexion Manual	Flexion CODA	Extension Manual	Extension CODA	Adduction Manual	Abduction CODA	Abduction Manual	Abduction CODA
1	78	86.5	53	82.5	20	3.5	68	18.4
2	86	89.6	55	84.5	26	7.4	46	14.3
3	77	84.7	87	75.9	30	6.9	65	17.9
4	90	89.3	67	82.6	24	0.2	75	17.5
5	61	77.3	67	80.0	25	13.0	89	25.5
6	73	86.9	77	87.9	31	2.7	75	23.1
7	73	89.1	74	87.0	31	2.6	64	22.6
8	74	84.8	65	81.4	35	8.5	69	19.5
9	71	85.4	44	95.8	20	4.4	63	18.7
10	57	89.5	63	86.5	21	4.6	41	36.5
11	76	86.9	66	86.4	85	9.4	39	59.1
12	77	87.2	61	88.3	28	2.3	56	15.9
13	80	88.6	67	90.6	31	17.2	56	33.8
14	76	87.9	68	85.3	26	0.7	60	15.7
15	76	90.2	70	90.1	33	4.3	60	16.3

Table 3, A summary of issues when using manual and motion capture techniques for goniometric measurement.

	manual Goniometry	Motion capture
Cost	£100 plus operator training	£80,000 plus operator training.
Preparation	None	Scanner and computer set up 30 minutes, 15 minutes to place markers per subject.
Measurement	5 minutes per Subject	40 seconds per subject.
Analysis of motion	Single measurement value. Dependent upon skill of operator.	Multi-angle analysis possible, variable view stick figure for orientation during analysis. Replay facility. Dependent upon skill of operator in maker placement.
Post processing	Manual data input to spreadsheet 2 minutes.	Analysis of stick figure diagram, graph plot and transfer to spreadsheet 15 minutes.
Portable	Yes	Yes, but can only be used under artificial lighting and requires an power supply.