Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
International Journal of Industrial Ergonomics 34 (2004) 139–147
International Journal of Industrial Ergonomics
www.elsevier.com/locate/ergon

Weaving posture analyzing system (WEPAS): introduction and validation

Alireza Choobineh[a,*], Mostafa Hosseini[b], Mohammadali Lahmi[c], Saeed Sharifian[d], Arash Hashemi Hosseini[d]

[a] *Department of Occupational Health, School of Health, Shiraz University of Medical Sciences, P.O.Box 71645-111, Shiraz, I.R. Iran*
[b] *Department of Epidemiology and Biostatistics, School of Public Health and Institute of Public Health Research, Tehran University of Medical Sciences, Tehran, I.R. Iran*
[c] *Department of Occupational Health, School of Public Health and Institute of Public Health Research, Tehran University of Medical Sciences, Tehran, I.R. Iran*
[d] *Engineering Research Institute, Jihad-Agriculture Ministry, Tehran, I.R. Iran*

Received 23 May 2003; received in revised form 29 March 2004; accepted 30 March 2004

Abstract

As a part of a comprehensive ergonomic study on hand-woven carpet weaving operation, in order to measure working posture, weaving posture analysis system (WEPAS), a two-dimensional video-based system for recording and analyzing weaving posture, based on image processing technology, has been developed. The reproducibility and accuracy of angle measurement obtained by use of WEPAS have been evaluated using a standard goniometer. The low standard deviations ($<1^\circ$) and insignificant variations due to analysis repetitions indicate high reproducibility of WEPAS. WEPAS accuracy test has revealed that under the defined condition the size of error is small ($<\pm1^\circ$). In different combinations of angle and rotation (movement in horizontal plane), the size of errors falls within -3°–1.6° indicating acceptable accuracy for the objective of our study. Low cost of WEPAS, along with its highly reproducible, relatively accurate measurements as well as its easy set-up and calibration have made it applicable system for postural analysis in weaving operation.

Relevance to industry

This two-dimensional posture analysis system can be applied in hand-woven carpet operation which is an important, widespread profession in Iran. The results of postural variables measurement can then be used to develop guidelines for workstation design to minimize postural strain during weaving operation. With some programming modifications, the system can be applied for posture analysis in other sedentary activities.

Keywords: Working posture measurement; Image processing technique; Hand-woven carpet weaving operation; 2D video-based technique

*Corresponding author. Present address: Department of Occupational Health, School of Health, Shiraz University of Medical Sciences, P.O.Box 71645-111, Shiraz, Iran. Tel.: +98 917 118 4450; fax: +98-711-7260225.
E-mail address: alrchoobin@sums.ac.ir (A. Choobineh).

0169-8141/$ - see front matter
doi:10.1016/j.ergon.2004.03.004

1. Introduction

Work situation may be analyzed in various ways. These range from work study to job analysis to task analysis and finally to posture analysis. An association between poor working postures and development of musculoskeletal disorders (MSDs) in diverse body regions has been discussed in the recent ergonomic literature (Duncan and Ferguson, 1974; Hunting et al., 1981; Aarås et al., 1988; Sauter and Schleifer, 1991; DE Wall et al., 1991; Haslegrave, 1994). In ergonomics, some postures are considered to be a serious risk factor for discomfort, reduced efficiency and MSDs (Grandjean et al., 1983; Bhatnager et al., 1985; Haslegrave, 1994; Li et al., 1995). Postural data are often used to estimate the biomechanical load on the musculoskeletal system (Paul and Douwes, 1993). The investigation of working posture requires an approach in which posture may be assessed accurately with minimal interference to the subject or the normal working environment (Wrigley et al., 1991). Various methods are now available for recording and assessing working posture. These include subjective observational methods such as OWAS (Karhu et al., 1977), posture targeting (Corlett et al., 1979) and RULA (McAtamney and Corlett, 1993) which yield information that is often relatively crude in comparison with the subtleties of the postures under analysis (Wrigley et al., 1991) and at the other extreme, commercially available systems for sophisticated accurate three-dimensional biomechanical human motion analysis (e.g. VICON, Selspot, SIMI Motion, APAS). These also suffer from some limitations for postural analysis (Wrigley et al., 1991) above all very high cost and complex set-up and calibration procedures. So, the budget and expertise to acquire and use the equipment and to process the data are not always available. Moreover, the use of such advanced recording and computational techniques is not always necessary to answer a specific research question (Paul and Douwes, 1993).

In our study, we wished to analyze working posture of workforce involved in hand-woven carpet weaving operation which was a sedentary work in type by an accurate, easy means that would provide useful information on weaving posture. Therefore, based on computer video image processing technology, a system for weaving posture analysis (WEPAS) was developed to attempt to overcome the disadvantages of the other approaches. The availability and low cost of image processing technology was encouraging factor to utilize this technology for posture analysis. Wrigley et al. (1991) used this approach to analyze working posture of keyboard operators. The purpose of this paper is to describe the system as well as to present its validation method and results. Data obtained using WEPAS to analyze the posture of weavers will be presented in a separate paper.

2. Methods

2.1. Description of the system

In the absence of twisting, lateral bending, limb abduction and rotation around the length axis of body, two-dimensional (2D) biomechanical models can be used, for which 2D postural angles are required as input. These data can be provided by 2D posture recording and description (Paul and Douwes, 1993). The working posture under examination in this study was largely 2D such that the most limbs movement occurred in sagital plane. It was, therefore, felt that the objectives of the project could be met with 2D analysis. Consequently, WEPAS equipped with a single camera was developed for analyzing working posture of weavers during weaving operation. WEPAS components are as follows (Fig. 1):

1. SONY Hi8 video camera recorder model no. CCD-TR705E. The workers' motions in weaving operation are slow enough to use a standard camera with frame rate of 25 Hz.
2. Panasonic NV-SD320 video recorder.
3. Computerized image processing system for analyzing the video recordings. The system includes
   (A) IBM compatible computer (1700 MHz Pentium 4 processor, 512 MB RAM, 40 GB hard disk, Windows 98).

Fig. 1. The components of WEPAS. Video camera, video recorder, computer equipped with capture card and installed WEPAS software are parts of this system.

(B) ASUS V7100 DELUXE COMBO graphic card for digitizing video signals.
(C) WEPAS software to perform the operations necessary to analyze captured frames and measure postural angles. This software was written utilizing Object Pascal language.

2.2. Recording procedure

An experimental weaving workstation was constructed in the laboratory. The camera was placed in a constant distance of 5 m from the weaver and connected to the video recorder. In order to measure weaving postures, small semi-spherical reflective markers with 2 cm of diameter were placed on the right side of the weaver's body that faced the video camera on the defined anatomical landmarks (Fig. 2). The weaver was asked to wear dark clothing, and marker attachment was made to skin or tight fitting clothing (Fig. 2). In order to facilitate tracking wide ranging movement of forearm, a cylindrical linear marker extended from humerus lateral epicondyle to styloid process of ulna was used. For the purpose of the seated postural analysis, the system measures six postural variables including head inclination (HI), neck inclination (NI), trunk inclination (TI), trunk angle (TA), arm angle (AA) and elbow angle (EA) as shown in Fig. 3.

Fig. 2. A weaver is working in the experimental workstation. The horizontal and vertical reference lines (level and plumb lines, respectively) are seen in the picture. The reflective markers are attached on the anatomical landmarks including outer canthus, tragus, C7, greater trochanter, greater tubercle, lateral humeral epicondyle, styloid process of ulna and lateral femoral epicondyle.

2.3. The software of WEPAS

The aim of the image processing system is to detect the reflective markers in the video image. The co-ordinates of the markers are then used to compute the weaver's postural variables.

After a recording session, the composite output from the video recorder is converted into graphic signal by the capture card and a file with .avi format is produced. After running the WEPAS software, the produced .avi file has to be loaded and a .dat file is to be defined for data storage. On the first frame, as the reference frame, the following interactive adjustments should be performed (Fig. 4):

(A) *Scaling:* horizontal and vertical reference lines, as well as definite lengths on these references are defined.
(B) *Marker assignment:* the placements of markers are defined and their co-ordinates are determined.
(C) *Contrast threshold:* The contrast between the white markers and dark background is optimized for improving marker detection.

In frame analysis, the co-ordinates of each of the markers for each frame are determined by the software and a 'windows region' is computed to surround each marker. These windows can be dynamically moved with each new marker position to track wide ranging movements. If the software cannot detect any of the markers, the analysis process is stopped and an error message indicating the problem appears. Then, the problem should interactively be removed by the user. If the two or three markers necessary to compute any given postural angle are located in an image, the

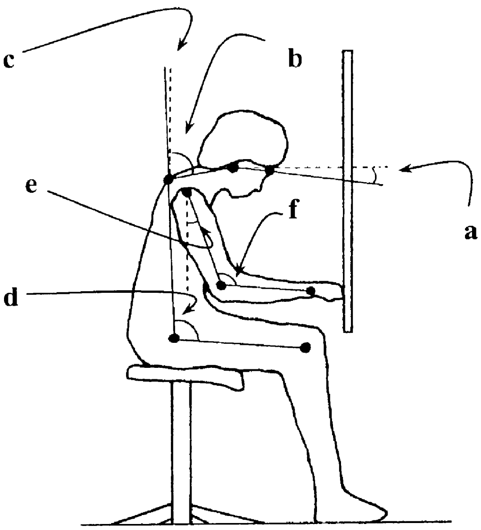

Fig. 3. Postural angles measured by WEPAS. Dotted lines are horizontal and vertical reference lines. a = HI, b = NI, c = TI, d = TA, e = AA and f = EA.

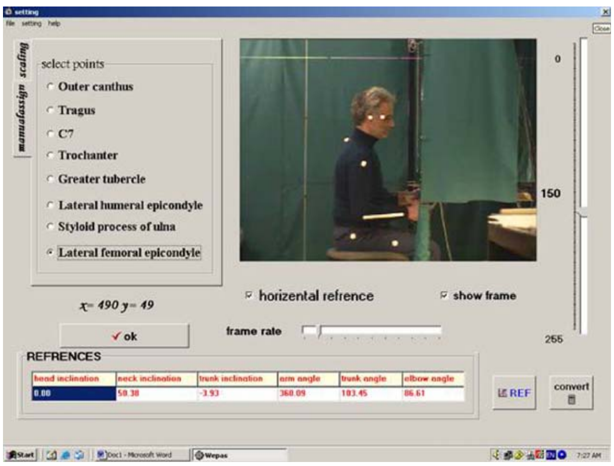

Fig. 4. The WEPAS software main page. Scaling, marker assignment (left) and the slider for contrast threshold adjustment (right) are shown.

software performs the trigonometric computations necessary to drive the angle. A frame can be fully processed and the measurement results stored in nearly 1.5 s. Upon completion of an analysis session, graphic reports of the changes in postural variables over time, as well as descriptive statistics are available. Raw data are also transferable to statistical software (i.e. SPSS) for further statistical analysis.

2.4. System validation procedures and results

Validation of the system was conducted in terms of reproducibility and accuracy.

The reproducibility of WEPAS was determined using a two fold approach including static and dynamic tests in which zeroth-order and first-order replication levels experiments (Coleman and Glenn Steele, 1999) were conducted.

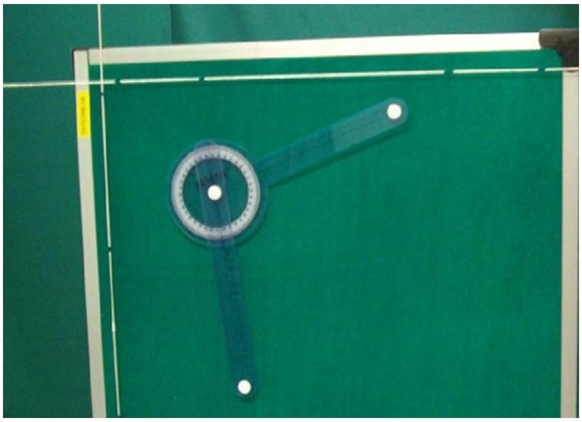

Fig. 5. Static test. Reflective markers attached to a standard goniometer.

Static tests: Passive reflective markers, 1 cm in diameter, were attached to the axis near the end of each 24 cm arms of a clear goniometer. Four angles including 10°, 45°, 95° and 145° were used as reference angles. At each of these reference angles, the reflective markers on the goniometer were recorded for 10 s in a defined condition from the viewpoint of camera setting and location (Fig. 5). Under these conditions, a series of zeroth- and first-order replication levels experiments, were conducted. In each, 30 frames were analyzed in three diverse trials. The results are presented in Table 1. One-way analysis of variance indicated that in the zeroth-order replication level experiment there was no significant difference between the results of the three trials (Table 1). One-way analysis of variance also showed that analyzing different frames under identical conditions had no significant effect on angle measurement for the reference angles of 10°, 45° and 145° (Table 1). Despite small variations, the differences for angle 95° were found to be significant; however, for practical purposes the difference between the means are so small that can be ignored.

Dynamic tests: To make an assessment on the system under dynamic, real conditions, in the experimental weaving workstation a professional weaver was asked to perform the weaving task (Fig. 2). He was recorded for 30 min and postural variables were measured. The results showed no

Table 1
The results of zeroth- and first-order replication levels experiments for reproducibility test under static condition

Replication level	Reference angle (°)	Trial 1		Trial 2		Trial 3		p-value
		M (°)	SD (°)	M (°)	SD (°)	M (°)	SD (°)	
Zeroth-order	10	10.13	0.17	10.12	0.15	10.13	0.18	0.14
	45	45.18	0.04	45.17	0.03	45.17	0.03	0.44
	95	95.77	0.27	95.77	0.27	95.77	0.27	> 0.9
	145	145.14	0.62	145.14	0.62	145.14	0.55	> 0.9
Frame-wise first-order	10	10.13	0.17	10.11	0.18	10.12	0.18	> 0.9
	45	45.18	0.04	45.18	0.04	45.17	0.02	0.56
	95	95.77	0.27	96	0.35	95.09	0.37	0.001
	145	145.14	0.62	145	0.51	144.93	0.61	0.36

Table 2
The results of zeroth-order replication levels experiments for reproducibility test under dynamic conditions

Postural variable	Trial 1		Trial 2		Trial 3		*p*-value[a]
	M (°)	SD (°)	*M* (°)	SD (°)	*M* (°)	SD (°)	
HI	13.7	4.43	13.78	4.24	13.7	4.43	> 0.9
NI	35.25	2.97	35.28	3.02	35.25	2.97	> 0.9
TI	−6.41	0.63	−6.42	0.63	−6.43	0.62	> 0.9
AA	27.61	9.3	27.59	9.31	27.59	9.31	> 0.9
TA	100.68	0.83	100.68	0.83	100.7	0.82	> 0.9
EA	88.99	6.77	88.96	6.76	88.96	6.76	> 0.9

In each trial, 32 frames were analyzed.
[a] One-way ANOVA.

significant differences between trials for the six postural angles (Table 2).

Study of the effect of image resolution on angle measurement revealed that low resolution images yielded more accurate results.

To assess the accuracy of angle measurement by WEPAS, angles between 10° and 145°, in 10° increments, were used as reference angles. At each of the reference angles, the reflective markers on the goniometer were recorded for 10 s. The camera setting, position and its distance to the subject (goniometer) were the same as real weaving postural angle measurement conditions. The video tape was, then, captured in low resolution. Thirty frames were analyzed and the means were compared to the reference angles. Table 3 presents the results of accuracy experiments. Inspection of Table 3 shows that in this range of angle (10°–145°) the angle measurement error is less than 1° which seems pretty acceptable for the objective of weaving posture measurement.

In order to assess WEPAS angle measurement accuracy in the six postural angles, a 2D manikin with eight articulations was made. Reflective markers were attached on the same points as a real subject (Fig. 6). Using the goniometer, the manikin limbs were fixed into different angles covering the typical range of motion for each of the postural variables measured, as indicated in Table 4. A single frame was extracted for each postural angle and analyzed. Direct comparisons were made between video-based postural angle determination and manually angle measurement using a goniometer. The effects of movement in horizontal plane on measurement accuracy were investigated, as well. The goniometer angle was subtracted from the image processing determined angle for each data point to determine the difference between the two methods (Table 4). Two-way analysis of variance was, then, conducted to determined the effects of angle and rotation in horizontal plane (+30°, +15°, 0°, −15° and −30°) on the postural variables.

Inspection of Table 4 shows that for all postural variables, when the rotation is in +15° to −15° range, the differences in angles between the two methods are relatively small and probably fall

Table 3
Mean of WEPAS-calculated angles for each reference angle and their differences with the related reference angles

Reference angle (°)	WEPAS-calculated angle (°)		Difference (°) (calculated–ref.)
	M	SD	
10	10.27	0.16	0.27
15	15.64	0.08	0.64
25	25.28	0.02	0.28
35	35.41	0.06	0.41
45	45.05	0.03	0.05
55	55.14	0.12	0.14
65	64.5	0.16	−0.5
75	75.5	0.12	0.5
85	85.11	0.08	0.11
95	94.94	0.28	−0.06
105	105.2	0.21	0.2
115	115.39	0.17	0.39
125	125.18	0.35	0.18
135	134.99	0.45	−0.01
145	145.19	0.62	0.19

Fig. 6. The manikin used for determination of postural angle measurement accuracy. Markers are attached on the same landmarks as a real subject. Reference lines are visible in the picture.

within the error margin of angles determined using a goniometer. Two-way analysis of variance revealed that, in general, there was no significant variation due to angle for postural variables ($\alpha = 0.01$); however, for HI this was found to be significant. This indicates that WEPAS determines the angles accurately over the range of motion normally used by a weaver in weaving operation and is not sensitive to any specific angle. Two-way analysis of variance also showed that there was a significant effect due to rotation for all postural variables except for TI. This indicates that deviation from 2D movement will affect the accuracy of angle measurement considerably.

3. Discussion

The low standard deviations ($<1^\circ$) in static tests (Table 1) and insignificant variations due to analysis repetitions in static and dynamic tests indicate that the reproducibility of WEPAS is excellent. It proves WEPAS to be a reliable system for postural variable measurement. WEPAS accuracy test with goniometry (Table 3) revealed that under the defined condition the size of error was small ($<\pm 1^\circ$). In a study on a 3D motion analysis video system, Vander Linden et al. (1993) reported the mean system-calculated angles to be within 0.6° of the reference angle from 20° to 160°. Regardless of angle measurement conditions, the size of errors in the two studies seems to be close and nearly the same.

WEPAS accuracy tests with the manikin indicated that with no rotation, WEPAS measured postural variables with relatively small error ($\pm 2^\circ$) which probably fell within the error margin of postural angles determined using a goniometer (Table 4). When rotation is occurred in $+15^\circ$ to -15° range, the size of error was still small. It can be concluded that under the defined condition WEPAS is relatively accurate system for 2D postural angle measurement. The grand average of postural angles (Table 4) falls within -3°–$+1.6^\circ$ range indicating acceptable accuracy in different combinations of angle and rotation.

The larger differences between the two methods when the rotation is $+30^\circ$ and -30° appear to be associated with perspective error due to considerable rotation (Paul and Douwes, 1993). For TI this difference is small even in rotation of $+30^\circ$ and -30°. The reason seems to be related to the nature of TI angle which is defined as the angle between the line passing through greater trochanter and C7 and vertical line (Fig. 3). Since rotation in horizontal plane does not affect this line, the difference between the two methods will be small and probably fall within the error margin of goniometry. The results may suggest that in angle measurement by a 2D method, rotation does not equally affect all postural variables measurements such that the less an angle is affected by rotation, the less the size of perspective error will be.

4. Conclusion

To analyze weaving posture and measure postural variables in hand-woven carpet weaving operation, WEPAS is an applicable, relatively accurate and very reproducible means. The cost

Table 4
Differences in degrees between postural variables as determined using video-based analysis (WEPAS) and direct goniometry

Postural variables	Angle (°)	Differences (°)					Average
		Rotation towards the camera (°)		Neutral (°)	Rotation away from the camera (°)		
		+30	+15	0	−15	−30	
Head inclination	+30	2.9	0.87	−0.55	−0.97	−0.12	0.43
	+15	3.58	0.19	0.74	−0.24	−1.29	0.60
	0	0.00	0.00	0.00	0.00	−2.29	−0.46
	−15	0.26	0.26	−0.19	−0.35	−1.76	−0.36
	−30	−3.66	−1.75	−0.66	−0.67	−3.54	−2.06
	Average	0.62	−0.09	−0.13	−0.45	−1.8	−0.37
Neck inclination	+35	−10.64	−4.53	−0.68	0.36	−1.49	−3.4
	+45	−8.4	−3.13	−.63	−2.73	−3.81	−3.74
	+60	−4.48	−2.22	−1.44	−0.46	−2.51	−2.22
	+75	−5.59	−2.39	−0.86	−0.62	−1.76	−2.24
	Average	−7.28	−3.07	−0.9	−0.86	−2.39	−2.9
Trunk inclination	−14	0.69	−0.03	0.6	0.91	1.69	0.77
	0	−0.51	0.44	1.4	1.63	1.55	0.9
	+18	−2.5	0.65	1.8	1.54	0.24	0.35
	Average	−0.77	0.35	1.27	1.36	1.16	0.67
Arm angle	0	−2.16	−.53	−0.09	−0.53	−0.5	0.76
	+15	−3.78	−1.95	−0.96	−1.1	−1.89	−1.94
	+30	−4.26	−1.59	0.38	−0.18	−2.49	−1.63
	+45	−5.35	−0.29	0.58	−0.96	−3.11	−1.83
	+60	−3.75	−2.34	0.1	−2	−4.68	−2.53
	Average	−3.86	−1.34	0.002	−0.95	−2.53	−1.74
Trunk angle	82	1.75	1.98	1.19	0.45	−1.13	0.85
	104	3.41	0.23	−0.73	−0.77	−1.36	0.16
	123	6.62	1.81	1.62	2.5	5.6	3.63
	Average	3.93	1.34	0.69	0.73	1.04	1.55
Elbow angle	105	−2.94	0.28	−0.66	−1.19	−1.83	−1.27
	90	−5.57	−0.26	−0.84	−0.06	−5.38	−2.42
	75	−5.52	−0.66	0.73	1.91	−3.84	−1.48
	60	−6.65	−0.96	1.11	−0.62	−4.9	−2.4
	45	−7.19	−2.06	−0.73	−1.5	−5.42	−3.38
	Average	−5.57	−0.73	−0.08	−0.29	−4.27	−2.19

of WEPAS is approximately US$ 2500. It is far less than the cost of sophisticated biomechanical analysis systems.

WEPAS calibration and set-up procedure is short and easy to do. However, in the workstation some arrangements such as dark surfaces and horizontal and vertical reference lines should be provided. WEPAS is a tailor-made system for analyzing working posture and measuring postural variables in weaving operation. However, with some modifications, it can be applicable for other seated works such as sewing, assembling, keyboarding, and other traditional sedentary activities. Finally, WEPAS is designed to be used in laboratory settings for a specific research activity. If it is going to be applied in a real working environment, programming modifications are necessary.

Acknowledgements

Research funding for this study was provided by Institute of Public Health Research, Tehran University of Medical Sciences, via project no. 241/81/38. The authors wish to thank Mr. H. Amiri from Engineering Research Institute for his valuable advice.

References

Aarås, A., Westgaard, R.H., Stranden, E., 1988. Postural angles as an indicator of postural load and muscular injury in occupational work situations. Ergonomics 31 (6), 915–933.

Bhatnager, V., Drury, C.G., Schiro, S.G., 1985. Posture, postural discomfort, and performance. Human Factors 27, 189–199.

Coleman, H.W., Glenn Steele, J.R.W., 1999. Experimentation and Uncertainty Analysis for Engineers. Wiley, New York.

Corlett, E.N., Madeley, S.J., Manenica, I., 1979. Posture targeting: a technique for recording working postures. Ergonomics 22, 357–366.

DE Wall, M., Van Riel, M.P.J.M., Snijders, C.J., Van Wingerden, J.P., 1991. The effect on sitting posture of a desk with a 10° inclination for reading and writing. Ergonomics 34 (5), 575–584.

Duncan, J., Ferguson, D., 1974. Keyboard operating posture and symptoms in operating. Ergonomics 17 (5), 651–662.

Grandjean, M., Hunting, W., Pidermann, M., 1983. VDT workstation design: preferred settings and their effects. Human Factors 25 (2), 161–175.

Haslegrave, C.M., 1994. What do we mean by a 'working posture'? Ergonomics 37 (4), 781–799.

Hunting, W., Läubli, T.H., Grandjean, E., 1981. Postural and visual loads at VDT workplaces: I. Constrained postures. Ergonomics 24 (12), 917–931.

Karhu, O., Kansi, P., Kuorinka, I., 1977. Correcting working postures in industry: a practical method for analysis. Applied Ergonomics 8, 199–201.

Li, G., Haslegrave, C.M., Corlett, E.N., 1995. Factors affecting posture for machine sewing tasks. Applied Ergonomics 26 (1), 35–46.

McAtamney, L., Corlett, E.N., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics 24, 91–99.

Paul, J.A., Douwes, M., 1993. Two-dimensional photographic posture recording and description: A validity study. Applied Ergonomics 24 (2), 83–90.

Sauter, S.L., Schleifer, L.M., 1991. Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task. Human Factors 33 (2), 151–167.

Vander Linden, D.W., Carlson, S.J., Hubbard, R.L., 1993. Reproducibility and accuracy of angle measurements obtained under static conditions with the motion analysis video system. Physical Therapy 72 (4), 300–305.

Wrigley, T.V., Green, R.A., Briggs, C.A., 1991. Microcomputer video image processing technology in working posture analysis. Applied Ergonomics 22 (1), 2–8.