Applied Ergonomics
— Paper 139
PII:S0003-6870(96)00053-1

Applied Ergonomics Vol 28, No. 2, pp 139–143, 1997

0003-6870/97 $10.00 + 0.00

ELSEVIER

Measurement variability in upper extremity posture among VDT users

Daniel J. Ortiz,[1] Michele Marcus,[2] Fredric Gerr[2,3], Wendy Jones[1] and Susan Cohen[2]

[1]*Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA, USA*
[2]*Rollins School of Public Health, Emory University, Atlanta, GA, USA*

(Received 24 November 1995; in revised form 18 June 1995)

Hand and arm posture while keying is frequently mentioned as a risk factor for upper extremity musculoskeletal disorders (UEMSDs) among video display terminal (VDT) operators. However, many epidemiologic studies have not included measures of posture of VDT operators, in part, because of the difficulty of assessing posture rapidly and reliably among large numbers of subjects. For a single measure of posture to be useful for estimating dose–response relationships between posture and risk of UEMSDs, the within-subject variability of the postural measure must be smaller than the between-subject variability of the postural measure. In addition, the measure must be stable over time. We estimate the ratio of between- to within-subject variability for manual goniometry by measuring six postural angles on six occasions among 19 subjects using VDTs. For each postural angle, between-subject variability was substantially and statistically significantly larger than within-subject variability. Stability of postural measures over time was sufficient to justify a single postural measurement in epidemiologic studies. We conclude that manual goniometry can provide useful information about upper extremity posture among VDT users for use in epidemiologic studies of UEMSDs.

Keywords: manual goniometry, posture, musculoskeletal disorder, video display terminal

Introduction

Hand and arm posture while keying is frequently mentioned as one of several risk factors for upper extremity musculoskeletal disorders (UEMSDs) among video display terminal (VDT) operators (Faucett and Rempel, 1994). However, many large studies of musculoskeletal disorders among VDT operators have not included any measures of posture as a possible risk factor (Knave *et al*, 1985; Stellman *et al*, 1987; Rossignol *et al*, 1987). Furthermore, observation of an association between posture and risk of musculoskeletal disorders among VDT operators has been inconsistent in studies in which postural measures have been made (Sauter *et al*, 1991; Hunting *et al*, 1981; NIOSH, 1992; NIOSH, 1993).

Certain methodologic and logistic problems contribute to the difficulty of incorporating postural measures into epidemiologic studies of UEMSDs. Specifically, a large number of subjects must be measured in an epidemiologic study in order to reliably determine whether associations between posture and musculoskeletal disorders exist. Therefore, to be feasible for use in epidemiologic studies, postural measures must be rapidly performed, relatively inexpensive and portable. Manual goniometry is one method of postural assessment that meets these performance requirements.

Manual goniometry is typically performed as an instantaneous measure. Posture, however, in many settings, is a dynamic variable which may change over time. This variability has led some investigators to question the value of single measures of posture for use as an exposure variable in epidemiologic studies. For example, after using manual goniometry for measurement of posture among VDT operators, one investigator cautioned 'important sampling bias may have been introduced by measuring employees at only one point in time... how reproducible the postural data at various times throughout the day is unknown' (NIOSH, 1992). The utility of a single postural measurement for postural exposure assessment in epidemiologic studies is dependent upon the stability of such postural measurements over time. A single measurement may be sufficient to characterize posture in a relatively static task such as operating a VDT. Determination of the stability of postural measures over time among VDT operators was one primary aim of the present study.

In addition to the stability of postural measures over

[3]Author to whom correspondence should be addressed

time for any given subject, another key issue in evaluating their utility for exposure assessment in epidemiologic studies is the magnitude of postural variability between subjects compared to the magnitude of postural variability within subjects. In other words, given the variability in posture from day-to-day for any given subject, can we still observe sufficient differences in posture between individuals to determine whether particular postures are associated with increased risk of UEMSDs? Although many studies of the reliability of goniometry are available (Hellenbrant *et al*, 1949; Hamilton and Lachenbruch, 1969; Gajodsik and Bohannon, 1987; Horger, 1990), none was designed to compare the magnitude of the variability between subjects to the magnitude of the variability within subjects. Determination of the magnitude of the variability between subjects to the magnitude of the variability within subjects was the second primary aim of the present study.

Methods

Subjects

Subjects were recruited from a major utility company and a large hospital in the metropolitan Atlanta region. Subjects working at a computer keyboard at least 2 h or more per day were eligible for participation. Nineteen subjects volunteered to participate in the study. All participants worked on standard QWERTY type keyboards with a numeric keypad on the right side of the keyboard. The ages of participants ranged from 22 to 49 years (mean age = 38.8). Seventeen of 19 subjects were female and 16 were right-hand dominant. Self-reported daily computer use ranged from 2 to 8 h (mean self-reported daily computer use = 5.9 h). All workstations were observed to include standard, fixed-height, non-adjustable desks and tables. All chairs were adjustable for height.

Design

Manual goniometry was used to measure six postural angles for 19 video display terminal operators by two raters on six occasions. Specifically, each participant was measured at the same time (within 30 min) in the morning and in the afternoon on Monday, Wednesday and Friday of the same week, by the two raters. Raters were blind to each others measurements.

Both raters in this study were professional ergonomists who had experience with the measurement of posture using goniometers in the field. After development of the measurement protocol, the ergonomists practiced by performing measurements, side by side, on six subjects, prior to the actual collection of study data.

Measurement of postural angles

Postural angles measured were wrist ulnar deviation, wrist extension, elbow angle, shoulder abduction, shoulder flexion and gaze angle. Infrequent occurrences of wrist radial deviation and wrist flexion were recorded as negative values of wrist ulnar deviation and wrist extension, respectively. A standard 12 inch goniometer marked in one degree increments was used for measurement of elbow angle, shoulder abduction, shoulder flexion and gaze angle, and a standard 6 inch goniometer marked in five degree increments was used for measurement of wrist ulnar deviation and wrist extension (North Coast Medical, Inc., San Jose, CA). In order to allow measurements relative to true vertical or horizontal, the 12 inch goniometer was modified by rigidly fixing one carpenter's level parallel and one carpenter's level perpendicular to one arm. In order to keep each rater unaware of the results of the other rater, each was provided with a six inch and a modified 12 inch goniometer to perform the measurements independently.

Anatomic landmarks and goniometer arm placement for each of the six measurements are provided in *Table 1*. Measurement methods were based on those used by other investigators in either the physical rehabilitation literature (LaStayo and Wheeler, 1994) or the occupational ergonomic literature (Maeda *et al*, 1982; Sauter *et al*, 1991). Each measurement session began while the subject was typing at his/her VDT. The subject was instructed to 'pause' while typing. After the first rater took a postural measurement, the second rater immediately took a measurement of the same postural angle. The two raters alternated first by subject. Measurements were recorded to the nearest degree. The time to complete each measurement session was typically between 5 and 10 min for both raters combined.

Statistical analysis

Overall means and standard deviations for each postural angle were calculated. We also calculated means for each postural angle stratified by time-of-day, day-of-week and individual rater. Variances between-subjects and within-subjects were estimated by the mean squares obtained from analyses of variance using

Table 1 Placement of goniometer pivot and arms for each postural measurement

Wrist ulnar/radial deviation
- Pivot placed on midpoint between ulnar and radial styloid processes
- First arm placed at the midline of dorsal aspect of the forearm
- Second arm aligned with the midline of the long finger metacarpophalangeal joint

Wrist flexion/extension
- Pivot placed on the radial styloid process
- First arm aligned with the radius
- Second arm aligned with the midline of the index finger metacarpophalangeal joint

Elbow angle
- Pivot placed on lateral epicondyle of the humerus
- First arm aligned with the acromion process of the shoulder
- Second arm aligned with the ulnar styloid process

Shoulder flexion/extension
- Pivot placed on lateral aspect of acromion process of the shoulder
- First arm aligned vertically (carpenter's level for reference)
- Second arm aligned with the lateral epicondyle of the humerus

Shoulder abduction/adduction
- Pivot placed on posterior aspect of acromion process of the shoulder
- First arm aligned vertically (carpenter's level for reference)
- Second arm aligned with posterior midline of upper arm

Gaze angle
- Pivot placed on the ectocanthus of the eye
- First arm aligned horizontally (carpenter's level for reference)
- Second arm aligned with center of video display screen

statistical analysis procedure 4V of the BMDP software package (Dixon, 1992). An F statistic was calculated as the ratio of the mean squares between subjects (18 degrees of freedom) to the mean squares within subjects (209 degrees of freedom) (Winer, 1971). The total number of degrees of freedom for the analysis of variance model was 227 (19 subjects × 3 days × 2 times × 2 raters − 1). The variability within-subjects was further partitioned into variability due to day-of-week, time-of-day, individual rater and the interactions between these variables (Kleinbaum *et al*, in press).

Results

The overall mean and standard deviation for each postural angle are presented in *Table 2*. Analyses of variance for each postural angle are summarized in *Table 3*. The variability within-subjects (mean squares within-subjects from the ANOVA model) includes the variability due to time-of-day, day-of-week and individual rater. For each postural angle, variances observed between subjects were substantially and statistically significantly larger than variances within-subjects.

The ANOVA model for shoulder flexion in which the variance components are provided is illustrated in *Table 4*. The sum of squares within-subjects is equal to the total of the sums of squares for day-of-week, time-of-day, individual rater, the interactions between these variables.

Time-of-day (morning vs afternoon) was significantly associated with mean gaze angle. The mean gaze angle observed in the morning was slightly smaller than that observed in the afternoon (8.4 deg. vs 9.4 deg., $p < 0.01$). No significant differences (main effects) in mean posture were observed between morning and afternoon for any of the five other postural angles measured. However, a significant ($p = 0.01$) two-way interaction between rater and time-of-day was observed for shoulder flexion (*Table 5*). The mean shoulder flexion angle obtained by Rater 1 was smaller in the morning than in the afternoon, while the mean shoulder flexion angles obtained by Rater 2 did not differ from morning to afternoon.

No significant main effects were observed for any of the mean postural angles by day-of-week. A significant ($p < 0.05$) two-way interaction was observed between rater and day-of-week for gaze angle (*Table 6*). The mean gaze angle obtained by Rater 1 was smaller on Friday than on Monday and Wednesday. The mean gaze angle obtained by Rater 2 did not vary by day-of-week.

Individual rater was significantly associated with mean ulnar deviation, mean shoulder flexion and mean gaze angle. Mean postural angles obtained by Rater 1 were smaller than those obtained by Rater 2 for ulnar deviation (8.5 deg vs 9.2 deg, $p = 0.04$), shoulder flexion (16.4 deg vs 18.4 deg, $p < 0.01$) and gaze angle (8.2 deg vs 9.6 deg, $p < 0.01$). No significant two-way interactions were observed.

Table 2 Overall means for postural angles (in degrees)

Postural angle	Mean*	(SD)
Ulnar deviation	8.8	(7.2)
Wrist extension	31.2	(13.9)
Shoulder flexion	17.4	(12.1)
Shoulder abduction	16.0	(7.2)
Elbow angle	105.0	(11.6)
Gaze angle	8.9	(6.8)

*The mean of 12 observations 19 subjects (228)

Table 3 Analyses of variance for postural angles

Postural angle	Variability* between subjects	Variability† within subjects	F	Prob
Ulnar deviation	258.85	33.85	7.76	< 0.01
Wrist flexion	1914.46	44.45	43.07	< 0.01
Shoulder flexion	1485.49	32.18	46.16	< 0.01
Shoulder abduction	344.17	27.16	12.67	< 0.01
Elbow angle	1141.93	47.46	24.06	< 0.01
Gaze angle	501.46	6.51	77.03	< 0.01

*Mean squares between subjects
†Mean squares within subjects

Discussion

In this study, six upper body posture angles were measured for 19 VDT operators by two raters on six

Table 4 Analysis of variance for shoulder flexion

Source of variation	Sum of squares	df	Mean squares	F
Between-subjects	26 738.82	18	1485.49	46.16*
Within-subjects	6726.25	209	32.18	
Day-of-week	303.58	2	151.79	1.69
Residual (Day-of-week)	3231.42	36	89.76	
Time-of-day	31.69	1	31.69	0.83
Residual (Time-of-day)	686.06	18	38.11	
Rater	242.21	1	242.21	18.23*
Residual (Rater)	239.20	18	13.29	
Day-of-week by time-of-day interaction	26.35	2	13.18	0.39
Residual (Day by time interaction)	1221.65	36	33.93	
Day-of-week by rater interaction	52.67	2	26.33	2.54
Residual (Day by rater interaction)	373.67	36	10.38	
Time-of-day by rater interaction	28.78	1	28.78	7.58*
Residual (Time by rater interaction)	68.31	18	3.79	
Day-of-week by time-of-day by rater interaction	16.42	2	8.21	1.45
Residual (Day-of-week by time-of-day by rater interaction)	204.25	36	5.67	

*$p < 0.01$

Table 5 Mean shoulder flexion angles by time-of-day and rater

Rater	Morning Mean (SD)	Afternoon Mean (SD)
Rater 1	15.65 (11.89)	17.11 (11.91)
Rater 2	18.42 (12.31)	18.46 (12.55)

$N = 38$

Table 6 Mean gaze angle by day-of-week and rater

Rater	Monday Mean (SD)	Wednesday Mean (SD)	Friday Mean (SD)
Rater 1	8.53 (6.77)	8.61 (6.90)	7.39 (5.31)
Rater 2	9.47 (7.56)	9.71 (7.71)	9.71 (6.18)

$N = 38$

occasions. The posture angles were assessed by manual goniometry on Monday morning and afternoon, Wednesday morning and afternoon, and Friday morning and afternoon of the same week. One objective was to determine the magnitude of postural variability within subjects in comparison to the variability between subjects. If the variability between subjects was sufficiently greater than the variability within subjects, then manual goniometry would be useful for distinguishing an individual subject's posture from that of another individual subject's posture in epidemiologic studies of the relationship between posture and UEMSDs among VDT operators.

A second aim of the study was to determine if any of the postural angles varied systematically by individual rater, time-of-day or day-of-week. Systematic differences in posture, if observed for these variables, would require standardization of them when goniometry is used for postural exposure assessment in epidemiologic studies of musculoskeletal health. The absence of systematic differences attributable to these variables, in combination with a favorable ratio of variance between subjects to variance within subjects, would suggest that a single postural measure, at any time, would be adequately representative of an individual subject's posture while operating a VDT.

Postural angles measured with manual goniometry, in this population of workers performing a fairly stationary task, were found to be substantially more variable between subjects than within subjects. The ratio of the variability between subjects to the variability within subjects ranged from nearly eight-fold for ulnar deviation to 77-fold for gaze angle. These results suggest that useful information about an individual subject's posture while keying, relative to other individual subjects' postures, can be obtained with manual goniometry. Therefore, manual goniometry provides sufficient precision for use in epidemiologic studies of the association between posture while using a VDT and risk of musculoskeletal disorders. In addition, small effects, only a few of which were statistically significant, on measured postural angle, were observed for rater, time-of-day and day-of-week. Of these three variables, the largest of the statistically significant effects was observed for individual rater, and was, however, only two degrees in magnitude. Therefore, manual goniometry of postural angles of the upper body, among individuals performing jobs similar to those enrolled in this study, can provide consistent results regardless of the time-of-day or day-of-week.

The mean postural angles obtained for wrist ulnar deviation, wrist flexion, shoulder flexion, elbow angle and gaze angle were similar to those found by NIOSH in a study of communications workers using VDTs (NIOSH, 1992). This suggests that measurement methodology used in the current study was consistent with that used by NIOSH.

Small but systematic differences between raters were found for mean ulnar deviation, mean shoulder flexion and mean gaze angle. In addition, individual rater was found to interact with time-of-day for mean shoulder flexion and to interact with day-of-week for mean gaze angle. In both of these interactions, postural measurements varied systematically by time-of-day or day-of-week for Rater 1, while Rater 2 made measurements that were substantially more consistent. A limitation of the current study is that only two raters were used. The raters were well trained in the methods used in the study. These results may not be generalizable to studies using a larger number of raters. However, the results do indicate that, under these conditions, the effect of rater is small. We suggest that investigators performing studies in which multiple raters are used consider ongoing evaluation of systematic differences between raters for inclusion in data analyses.

Among the remaining variables, time-of-day was associated with mean gaze angle and none of the other postural angles. The mean gaze angle observed in the morning was slightly smaller than that observed in the afternoon. No main effects were found between day-of-week and any of the six postural outcomes (the one interaction involving day-of-week was described above).

Although time-of-day and individual rater were significantly associated with one or more measurement of postural angle (main effect), absolute differences as a function of these variables were quite small. Specifically, across all results for which significant main effects were observed, the mean differences observed between raters were two degrees or less, and the mean difference observed between morning and afternoon measurement sessions for gaze angle was only one degree.

One possible concern about the study methods was the requirement for the participant to 'pause' while keying in order for the postural measurement to be made. For two reasons, we do not believe that this instruction produced biased results, however. First, each subject was asked to pause while keying in his/her usual manner. Raters reported that they observed no changes in posture as a result of the instruction to pause. Second, the study used a repeated measures design. Therefore, bias could be introduced into the results only if the subject assumed a posture that was different from his/her usual one in a manner that varied systematically with rater, time-of-day or day-of-week. Thus, it seems unlikely that the results observed are attributable to changes in posture resulting from the request for subjects to 'pause'.

Two observations made during the conduct of this study might be useful in further reducing the variability in measurements. First, although the raters did practice on six subjects prior to actual measurement for study purposes, additional training and practice might have resulted in greater consistency of measurement.

Second, the short-arm goniometer used to measure wrist deviation and flexion was marked at five degree increments and the raters had to estimate angles within this range. Error due to this estimation could be reduced by using a goniometer with markings at one degree increments.

In conclusion, among persons performing a fairly stationary VDT keyboard task, the results of the present study suggest that a single measure of posture can provide reliable and useful information about differences in posture between subjects for use in epidemiologic studies of exposure–effect associations. Concerns about the reliability and use of a single manual goniometric measure as a meaningful estimator of posture in epidemiologic studies of such populations appear to be unfounded.

Acknowledgements

This study was supported by a grant from the National Institute for Occupational Safety and Health (R01-OH03160). The authors thank Mr Grover Higgins of Georgia Power and Ms Moya Hambridge of Piedmont Hospital for their assistance in participant recruitment. The authors thank Ms Kate Bond for assistance with data management, and Drs David Kleinbaum, Richard Letz, Dana Flanders and Andrzej Kosinski of the Rollins School of Public Health at Emory University for suggestions about data analysis.

References

Dixon, W.J. (ed). 1992 *BMDP Statistical Software Manual*, Vol. 2 (BMDP Release 7), University of California Press, Berkeley, pp 1259–1310

Faucett, J. and Rempel, D. 1994 'VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors' *Am J Indust Med* **26**, 597–612

Gajodsik, R.L. and Bohannon, R.W. 1987 'Clinical measurement of range of motion: Review of goniometry emphasizing reliability and validity' *Phys Ther* **67**, 1867–1872

Hamilton, G.F. and Lachenbruch, P.A. 1969 'Reliability of goniometers in assessing finger joint angle' *Phys Ther* **49**, 465–469

Hellenbrant, F.A., Duvall, E.N. and Moore, M.L. 1949 'The measurement of joint motion III: Reliability of goniometry' *Phys Ther Rev* **29**, 302–306

Horger, M.M. 1990 'The reliability of goniometric measurements of active and passive wrist motions' *Am J Occup Ther* **44**, 342–348

Hunting, W., Laubli, T.H. and Grandjean, E. 1981 'Postural and visual loads at VDT workplaces I. Constrained postures' *Ergonomics* **24**, 917–931

Kleinbaum, D.G., Kupper, L.L., Muller, K.E. and Nizam, A. *Applied Regression Analysis and other Multivariable Methods*, Third Edition, Duxbury Press, Belmont, CA, *in press*

Knave, B.G., Wibom, R.I., Voss, M., Hedstrom, L.D. and Bergqvist, U.O.V. 1985 'Work with video display terminals among office employees I. Subjective symptoms and discomfort' *Scand J Work Environ Health* **11**, 457–466

LaStayo, P.C. and Wheeler, D.L. 1994 'Reliability of passive wrist flexion and extension goniometric measurements: A multicenter study' *Phys Ther* **74**, 69–83

Maeda, K., Hunting, W. and Grandjean, E. 1982 'Factor analysis of localized fatigue complaints of accounting machine operators' *J Human Ergol* **11**, 37–43

National Institute for Occupational Safety and Health 1992 HETA 89-299-2230, US West Communications, NIOSH, Cincinatti

National Institute for Occupational Safety and Health 1993 HETA 90-013-2277, Los Angeles Times, NIOSH, Cincinatti

Rossignol, A.M., Morse, E.P., Summers, V.M. and Pagnotto, L.D. 1987 'Video display terminal use and reported health symptoms among Massachusetts Clerical Workers' *J Occup Med* **29**, 112–118

Sauter, S.L., Schleifer, L.M. and Knutson, S.J. 1991 'Work posture, workstation design, and musculoskeletal discomfort in a VDT data entry task' *Hum Fac* **33**, 151–167

Stellman, J.M., Klitzman, S., Gordon, G.C. and Snow, B.R. 1987 'Work environment and the well being of clerical and VDT workers' *J Occup Behav* **8**, 95–114

Winer, B.J. 1971 *Statistical Principals in Experimental Design* McGraw Hill, New York, pp 283–296