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A Single Video Camera Postural Assessment System to Measure Rotation of the Shoulder During Computer Use

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The goal of this study was to evaluate the performance of a single video camera system for measuring shoulder rotation during computer work, and to quantify the work and postural space within which the system performs optimally. Shoulder rotation angles calculated using the video system were compared with angles calculated using an active infrared LED three-dimensional motion analysis system while 10 adult volunteers simulated postures for two different trials: typical of normal computer work (freestyle) and with forced shoulder abduction (constrained). Average and absolute errors were calculated to determine the accuracy and precision of the system, respectively, for each trial, for each position, and for both the right and left hands. For the right hand, mean values for the average and absolute errors were –1 and 0 degrees, respectively. Only the absolute error increased significantly to 12 degrees for the constrained posture compared with freestyle. During normal computer work, the video system provided shoulder rotation angle values similar to those of a three-dimensional system, thus making it a viable and simple instrument to use in field studies.

Keywords: motion analysis, musculoskeletal, computer use

Computers are a staple of the modern workplace. However, a growing body of evidence suggests that computer use may cause work-related upper extremity musculoskeletal disorders (MSDs), potentially as a result of non-neutral postures (Gerr et al., 2004; Ijmker et al., 2007; Marcus et al., 2002). Shoulder rotation, a suspected risk factor for neck and shoulder disorders, is one posture of concern (Karlqvist et al., 1998).

Measuring shoulder rotation in field studies is challenging. Discrete measurement methods (McAtamney & Nigel Corlett, 1993; Ortiz et al., 1997; James et al., 1997) are labor intensive and lack the detail of continuous measurements. Accelerometer-based systems (e.g., Faber et al., 2009) collect data continuously but are incapable of measuring shoulder rotation in the seated posture. Three-dimensional motion analysis systems can measure shoulder rotation continuously but are expensive and unwieldy to bring into the field.

Therefore, we have developed a single video camera system that measures shoulder rotation continuously during computer use. For this study, shoulder rotation is defined as the angle of the forearm with respect to the trunk, corrected for camera angle and shoulder abduction. The system is designed to estimate shoulder rotation using a two-dimensional image and a set of assumptions. Our goal was to evaluate the performance of this system compared with a three-dimensional motion analysis system (Optotrak, Northern Digital, Waterloo, Canada) under one set of conditions typical of normal computer work, and to quantify the work and postural space within which the system performs optimally.

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Methods

Recruitment and Experimental Protocol

A convenient sample of 10 adults (5 male, 26 [4] years) were recruited for this study. All protocols, recruitment materials, and consent forms were approved by the institutional review board.

To generate different postures to compare between the video and three-dimensional systems, participants performed trials consisting of moving their right or left hand to a series of locations defined by points on a grid marked on a desk in front of them (Figure 1). Participants performed two trials for each hand separately, for a total of four trials: gripping a computer mouse without any specific constraint on the orientation of the hand (freestyle trials), and aligning the 3rd metacarpal and middle

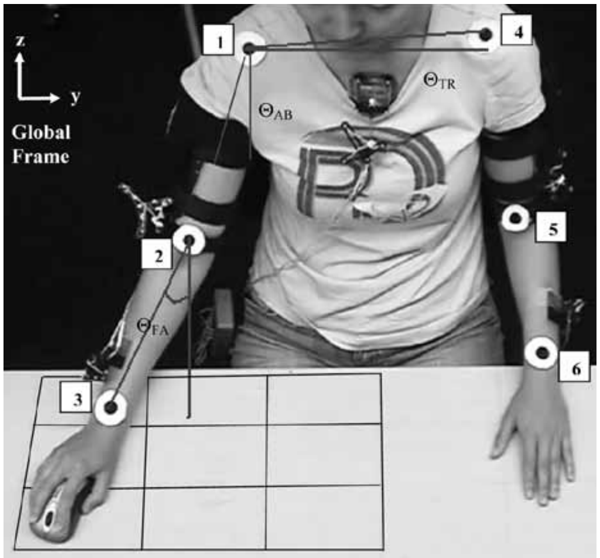

Figure 1 — View from the video camera, defining the video marker positions and angles used to calculate shoulder rotation angle. Each participant wore six black and white video markers to be tracked by the video system. Angles of the trunk, shoulder abduction, and shoulder rotation calculated by the video system are also shown. Also shown in the figure is the 3 × 3 grid used to define positions for the mouse and abduction trials. In this figure, the right-hand grid is accentuated for easy viewing. During the experiment, participants were able to see the markings of the grid during each trial without the accentuation. During this mouse trial, the participant is sitting with her left hand in the "neutral" position, which is also the correct positioning of the hand for abduction trials. The participant's right hand demonstrates the correct positioning of the hand for mouse trials.

fingertip with the lateral line defining each position with the middle fingertip touching the distal lateral corner of the rectangle (constrained trials). The freestyle trials were performed to emulate shoulder postures experienced during real computer work, while the constrained trials were performed to test the limits of the video system under conditions of increased shoulder abduction.

All trials were performed at a simulated workstation adjusted so that, with feet flat on the ground, each participant's thighs were horizontal and the workstation desk height was level with the seated elbow height. The grid was sized individually for each participant based on the location of a point marked at the participant's middle finger when the participant's fully extended arm was moved by a researcher 45 degrees laterally of the researcher's estimation of the participant's midline while the participant was sitting comfortably. The grid was then defined as the rectangle formed by connecting the participant's midline to the parallel and perpendicular lines extending from this point.

A neutral position was also defined and marked on the grid as the location of each participant's middle finger when the participant sat with upper arms and torso perpendicular to the ground, forearms perpendicular to the edge of the table and hands flat on the table. All angles were corrected by subtracting the angles calculated with the participant sitting in this neutral position.

During all trials, the posture of the upper arm was measured using both the single video camera system and a three-dimensional infrared marker optical motion analysis system (Optotrak, Northern Digital, Ontario).

Single Video Camera System

The proposed system consists of a single digital video camera (JVC Everio digital video camera), simple black and white markers, and custom designed software. The camera is mounted on a tripod high enough above the computer monitor so that the participant's hands, elbows and shoulders can be seen during computing (height: 140 [3] cm, angle (Θ_c): 57 [2] degrees for this experiment). Camera angle is measured as the angle between the camera's view perpendicular to the lens and horizontal.

Six hand-made markers are positioned approximately at each participant's left and right acromions, lower biceps, and wrists (Figure 1). The markers, which estimate joint centers, are made of small (1 in diameter) circular black felt stickers superimposed within 1.5 inch diameter white paper circles.

The 2-dimensional (y, z) positions of the six markers within the video image are determined through digital processing of the video footage recorded at 29.97 samples per second. In postprocessing, custom-designed digitizing software (VideoPos, developed by Microsoft Visual C++ 6.0) identifies markers in each video frame, outputting pixel coordinates. In MatLab, the data are cleaned to remove any points where the markers are not directly identified. The data are then filtered using a 4th-order low pass Butterworth filter with a cutoff frequency of 5 Hz.

Angle Calculations From the Video. We first calculate the angle of torso rotation as

$$\Theta_{TP} = \tan^{-1}[(z_1 - z_4) / (y_1 - y_4)] \quad (1)$$

where (y_1, z_1), (y_2, z_2), (y_3, z_3) and (y_4, z_4) denote the 2-D pixel location on the camera image for the (1) right acromion, (2) right elbow, (3) right wrist, and (4) left acromion markers (Figure 1). We also calculate shoulder abduction angle as

$$\Theta_{AP} = \tan^{-1}[(y_2 - y_1) / (z_2 - z_1)] \quad (2)$$

where Θ_{AP} in the equation above denotes the abduction angle of the right arm.

We next calculate the shoulder rotation angle corrected for the parallax effect due to camera angle (Lau & Armstrong 2011; Paul & Douwes 1993):

$$\Theta_{CR1} = \tan^{-1}\{(y_3 - y_2)/[(z_3 - z_2) / \sin(\Theta_C)]\} \quad (3)$$

where Θ_{CR1} is the right arm rotation angle corrected for the camera angle, and Θ_C is the camera angle with respect to the horizontal. We compared the results of correcting shoulder abduction angle and torso angle for camera angle but these corrections did not improve the accuracy of the shoulder rotation angle calculations; therefore, for simplicity, we choose to correct for camera angle in the shoulder rotation angle calculation only.

We then adjust the rotation angle for the observed shoulder abduction angle. As abduction increases, the orientation of the forearm in the horizontal plane is a combination of shoulder rotation and elbow flexion. To separate the rotation component, we calculate the projected vector of the forearm onto the plane normal to the upper arm. In addition, we need to isolate rotation from twisting of the torso. Therefore, the right adjusted rotation angle (Θ_{RR}) is calculated as

$$\Theta_{RR} = \sin^{-1}[\sin(\Theta_{CR1}) \times \cos(\Theta_{AP})] - \Theta_{TP} \qquad (4)$$

The same process is used to calculate the left arm rotation using (y_5, z_5) and (y_6, z_6) instead of (y_2, z_2), and (y_3, z_3). All angles are calibrated with respect to the reference posture by subtracting the angles calculated during the reference posture.

Three-Dimensional Measurements

To compare with the estimates of shoulder rotation given by the video system, shoulder rotation was measured using an Optotrak system, which can measure the three-dimensional location of markers at an accuracy of 0.1 mm. Participants were instrumented with five clusters of three infrared light-emitting diodes (IREDs) fixed to rigid surfaces and secured to the trunk, right arm, left arm, right forearm, and left forearm (Figure 1). Using a single camera bank consisting of three cameras, the locations of all 15 IREDs were tracked at 30 samples per second and data were recorded to a personal computer. After finishing the data collection, data were digitally filtered using a 4th-order low pass Butterworth filter with a cutoff frequency of 5 Hz.

Rotation matrices were calculated to obtain the orientation of the forearm, arm, and trunk with respect to a global reference frame. For the global reference frame, the X/Y plane was parallel with the desk surface and Z was normal to it (Figure 1). Euler angles were calculated from the rotation matrices to get shoulder rotation, abduction/adduction, and flexion/extension angles. Shoulder abduction/adduction was obtained from the rotation matrix relating the upper arm to the trunk such that the first xyz-rotation was shoulder abduction. Shoulder rotation angle was obtained from the third xyz-rotation matrix relating the forearm to the trunk as described by (Cutti et al., 2006). For a thorough discussion of rotation matrices and how they are used to calculate Euler angles, see Winter (2005). These rotation matrices and Euler angle data were processed using MatLab v. 7.0.4 (Mathworks, Natick, MA). The code used to process the three-dimensional data were validated using known angles.

Data Analysis and Statistics

For every participant, rotation angles for both the video system and the three-dimensional motion analysis system were obtained for each hand in each position for every trial. Each value was extracted by averaging angle data after the hand had reached the position and stopped moving.

To evaluate the differences between the rotation angles calculated from the video system compared with three-dimensional system, errors were calculated by subtracting the rotation angle calculated for the three-dimensional system from the rotation angle calculated for the video system. The average error for each position, a measure of accuracy of the video system for calculating rotation angle, was calculated by averaging the error for each participant across all participants. Absolute error, a measure of the video system's precision, was calculated by averaging the absolute error calculated for each participant at each position across all participants. Standard deviations were calculated as well. The mean average error and absolute error, along with their corresponding standard errors, were calculated by averaging each error type over all positions. Two-sided, unpaired *t* tests ($\alpha = .05$) were performed to test whether the overall average and absolute errors differed between freestyle and constrained trials for the right and left hands, separately.

To evaluate whether the constrained conditions induced greater shoulder abduction compared with the freestyle trials, the range of motion (maximum-minimum) for angles of shoulder abduction (calculated from the three-dimensional data) was calculated. Paired *t* tests ($\alpha = .05$) were used to compare the range of motion for shoulder abduction between the freestyle and constrained conditions.

Results

Rotation angles ranged from –25 degrees (25 degrees of internal rotation) to 26 degrees of external rotation, and were similar for the four trials (Figures 2 and 3).

Average and absolute errors were similar across all positions, and the absolute error was smaller for the freestyle than the constrained trials (Figures 2 and 3). The mean average errors were small for each trial (freestyle: left = 1 degree, right = –1 degree; constrained: left = –1 degree, right = 1 degree) and not significantly different between the freestyle and constrained trials ($p = .24$ for the left and $p = .60$ for right hand, Table 1), indicating that the video system is precise. The mean absolute errors across all positions were smaller for the freestyle trials than the constrained trials ($p = .03$ for the left and $p < .001$ for right hand, Table 1).

The *t* tests comparing the freestyle and constrained trials showed significantly less abduction range of motion in the mouse trials for both the right ($p < .001$) and left ($p = .01$) hands (Table 2).

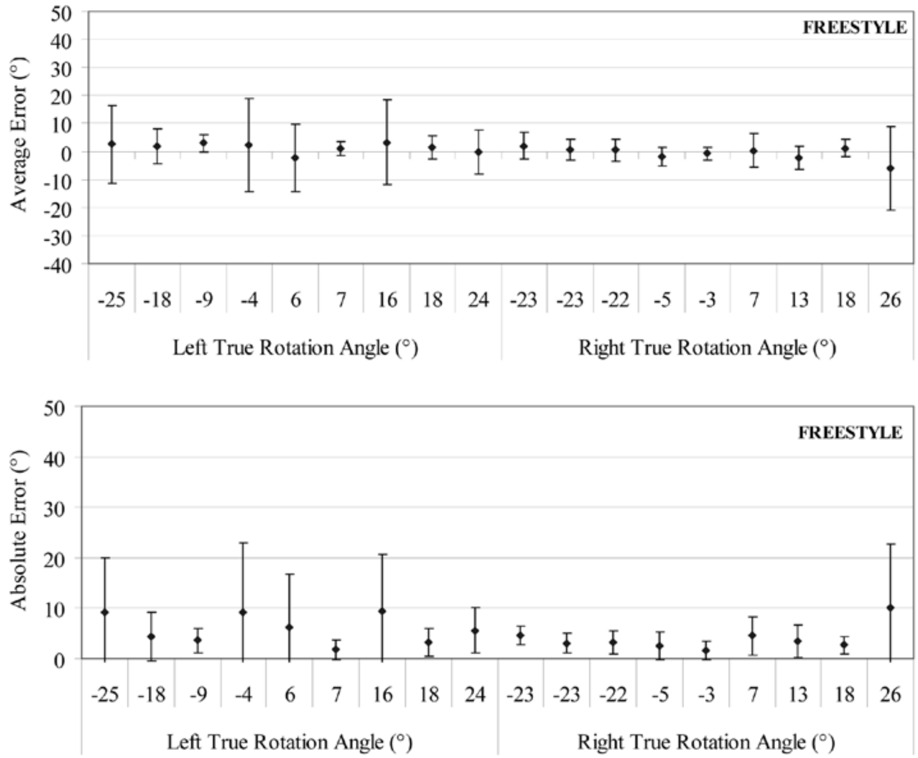

Figure 2 — Across subject mean values for the average and absolute error for shoulder rotation in the freestyle condition. Bars represent one standard deviation. The x-axis represents the average shoulder rotation angle (calculated from the three-dimensional system) recorded during each of the nine positions tested in Figure 1. Negative values represent internal rotation, and positive values represent external rotation.

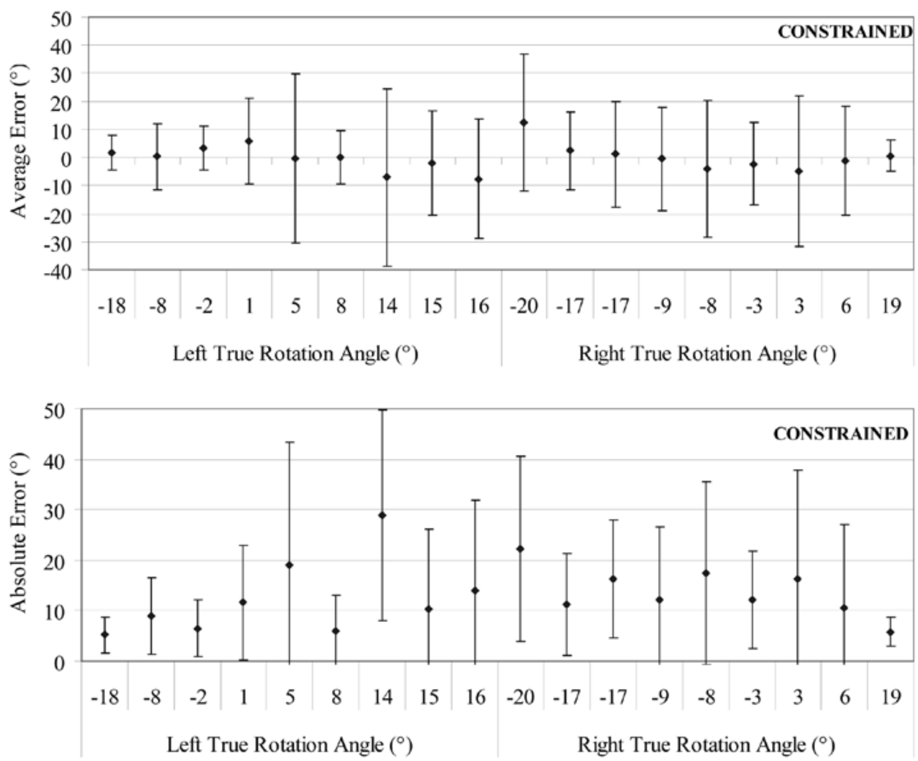

Figure 3 — Across subject mean values for the average and absolute error for shoulder rotation in the constrained condition. Bars represent one standard deviation. The x-axis represents the average shoulder rotation angle (calculated from the three-dimensional system) recorded during each of the nine positions tested in Figure 1. Negative values represent internal rotation, and positive values represent external rotation.

Table 1 Shoulder rotation average and absolute error (in degrees) averaged across all participants and all positions, with standard errors

	Average Error		Absolute Error	
	Left	Right	Left	Right
Freestyle	1° (0.2°)	–1° (0.3°)	**6° (0.3°)**	**4° (0.3°)**
Constrained	–1° (0.5°)	0° (0.6°)	**11° (0.7°)**	**12° (0.5°)**
T-test (Freestyle vs. Constrained)	$p = 0.24$	$p = 0.60$	$\mathbf{p = 0.03}$	$\mathbf{p < 0.01}$

Note. **Bold** column values indicated significant ($p < 0.05$) differences between freestyle and constrained trials. Errors are shown for the left and right hands and for the constrained and freestyle trials. There were no significant differences for average errors when comparing freestyle and constrained trials. Overall absolute errors were significantly smaller for the freestyle trials than the constrained trials. Errors were similar for the right and left hands.

Table 2 Shoulder abduction range of motion and standard errors (in degrees), averaged over all participants and all positions

	Abduction Range of Motion (Standard Error)	
	Left	Right
Freestyle	**24.5° (0.7°)**	**22.3° (0.6°)**
Constrained	**31.0° (0.7°)**	**35.7° (0.8°)**
T-test (Freestyle vs. Constrained)	**p = 0.01**	**p < 0.01**

Note. **Bold** column values indicated significant ($p < 0.05$) differences between freestyle and constrained trials. Errors are shown for the right and left hands and for the freestyle and constrained trials. The range of motion was significantly greater for the constrained than the freestyle trials for both the left ($p = 0.01$) and right ($p < 0.01$) hands.

Discussion

Our goal was to develop and test a video system designed to measure internal and external shoulder rotation during computer use. Our results indicate that during the freestyle trials, the video system performed well compared with the more sophisticated three-dimensional system: low overall average and absolute errors were observed for all positions. Since the positions tested during the freestyle trials were typical of postures associated with computer users, we can conclude that the video system can be used to measure shoulder rotation in studies of computer users performing similar tasks to the freestyle trial tested here, under similar conditions.

The single video camera system is less expensive and more portable than the three-dimensional system, while giving similar results. This system can take direct, continuous measures of shoulder rotation for extended periods of time in the field. The video system is noninvasive, allowing workers to use their computers without constraint and to leave the camera's view. The tracking software is automatically able to capture markers that have left and reentered the screen.

The results of this validation study must be taken with consideration to the system's limitations as it is presented here. Several assumptions were made when calculating the shoulder rotation angles, including that the forearm is parallel to the ground, that the torso is perpendicular to the ground, and that there is no shoulder flexion or extension. In addition, this experiment demonstrated that the video system was susceptible to increased absolute error during the constrained trials (Figures 2 and 3, Table 1). The constrained trials, which were designed to test the limits of the video system for measuring shoulder rotation with increased abduction and were not meant to generate realistic postures experienced during computer use, did generate a greater range of shoulder abduction postures than the mouse trials did (Table 2). Although the postures that must be assumed to fit the requirements of the video system are realistic for normal computer use, the system will not be as reliable in situations where they are not met.

The results of this validation study must also be taken within the confines of the study. The video system was only tested under specific conditions during this experiment. The postures and marker movement speeds tested were limited to those experienced during normal keyboard and mouse use at a seated computer workstation. The only camera position validated during this study was a top view of the user with the camera placed directly behind the user's monitor. Only an indoor office environment lighting condition was tested. The small sample size could also have affected the results.

Although further testing should be done to use the video system in the situations mentioned above, for measurements in the conditions tested here, the video system provides accurate results of internal and external shoulder rotation.

References

Paul, J.A., & Douwes, M. (1993). Two-dimensional photographic posture recording and description: a validity study. *Applied Ergonomics, 24,* 83–90. PubMed doi:10.1016/0003-6870(93)90079-O

Cutti, A., Cappello, A., & Davalli, A. (2006). In vivo validation of a new technique that compensates for soft tissue artefact in the upper-arm: Preliminary results. *Clinical Biomechanics (Bristol, Avon), 21,* S13–S19. PubMed doi:10.1016/j.clinbiomech.2005.09.018

Gerr, F., Marcus, M., & Monteilh, C. (2004). Epidemiology of musculoskeletal disorders among computer users: lesson learned from the role of posture and keyboard use. *Journal of Electromyography and Kinesiology, 14,* 25–31. PubMed doi:10.1016/j.jelekin.2003.09.014

Faber, G.S., Kingma, I., Bruijn, S.M., & van Dieën, J.H. (2009). Optimal inertial sensor location for ambulatory measurement of trunk inclination. *Journal of Biomechanics, 42,* 2406–2409. PubMed doi:10.1016/j.jbiomech.2009.06.024

Ijmker, S., Huysmans, M.A., Blatter, B.M., van der Beek, A.J., van Mechelen, W., & Bongers, P.M. (2007). Should office workers spend fewer hours at their computer? A systematic review of the literature. *Occupational and Environmental Medicine, 64,* 211–222. PubMed doi:10.1136/oem.2006.026468

James, C.P.A., Harburn, K.L., & Kramer, J.F. (1997). Cumulative Trauma Disorders in the Upper Extremities: Reliability of the Postural and Repetitive Risk-Factors Index. *Archives of Physical Medicine and Rehabilitation, 78,* 860–866. PubMed doi:10.1016/S0003-9993(97)90201-X

Karlqvist, L.K., Bernmark, E., Ekenvall, L., Hagberg, M., Isaksson, A., & Rostö, T. (1998). Computer mouse position as a determinant of posture, muscular load and perceived exertion. *Scandinavian Journal of Work, Environment & Health, 24,* 62–73. PubMed doi:10.5271/sjweh.279

Lau, M.H., & Armstrong, T.J. (2011). The effect of viewing angle on wrist posture estimation from photographic images using novice raters. *Applied Ergonomics*, 42, 634–643. http://dx.doi.org/10.1016/j.apergo.2010.08.008

Marcus, M., Gerr, F., Monteilh, C., Ortiz, D.J., Gentry, E., Cohen, S., . . . Kleinbaum, D. (2002). A prospective study of computer users: II. Postural risk factors for musculoskeletal symptoms and disorders. *American Journal of Industrial Medicine, 41,* 236–249. PubMed doi:10.1002/ajim.10067

McAtamney, L., & Nigel Corlett, E. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics, 24,* 91–99. PubMed doi:10.1016/0003-6870(93)90080-S

Ortiz, D.J., Marcus, M., Gerr, F., Jones, W., & Cohen, S. (1997). Measurement variability in upper extremity posture among VDT users. *Applied Ergonomics, 28,* 139–143. PubMed doi:10.1016/S0003-6870(96)00053-1

Winter, D. (2005). *Biomechanics and Motor Control of Human Movement* (3rd ed.). Hoboken: John Wiley and Sons, Inc.