Proceedings of the Human Factors and Ergonomics Society Annual Meeting
http://pro.sagepub.com/

Wrist and Forearm Postures and Velocities in Repetitive Precision Tasks

Kathleen Shyhalla, Victor Paquet and Colin Drury

Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2002 46: 1041
DOI: 10.1177/154193120204601308

The online version of this article can be found at:
http://pro.sagepub.com/content/46/13/1041

Published by:
SAGE
http://www.sagepublications.com

On behalf of:
HF ES
Human Factors and Ergonomics Society

Additional services and information for *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* can be found at:

Email Alerts: http://pro.sagepub.com/cgi/alerts

Subscriptions: http://pro.sagepub.com/subscriptions

Reprints: http://www.sagepub.com/journalsReprints.nav

Permissions: http://www.sagepub.com/journalsPermissions.nav

Citations: http://pro.sagepub.com/content/46/13/1041.refs.html

>> Version of Record - Sep 1, 2002

What is This?

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012

WRIST AND FOREARM POSTURES AND VELOCITIES IN REPETITIVE PRECISION TASKS

Kathleen Shyhalla
Victor Paquet
Colin Drury
Industrial Engineering
University at Buffalo
Buffalo, New York

Precision work has been shown to impose physical demands over and above similar work that does not require precision, but few studies have evaluated the effects of such work on the musculoskeletal stress of the upper extremities. Repetitive tasks that involved moving between a Home disk and a precision target were studied. The movements from the Home to the target were divided into a ballistic phase, followed by a slower homing-in phase. Work in two layouts, with the target in front of, or to the side of the Home disk, and three levels of precision were investigated for each phase of the home-to-target movement. Wrist and forearm postures and joint velocities were significantly different ($P < 0.05$) during the ballistic and homing in phases of travel for 21 of the 24 indices considered. Postures changed rapidly during the ballistic, but were sustained during the homing-in phase. Work in the forward versus side layouts produced statistically different joint angles and velocities ($P < 0.05$) for 17 of the 24 indices considered. Different levels of task precision elicited statistically differences in 5 of the 12 joint velocities ($P < 0.05$).

Interactions were also important. The phase of movement factor produced statistically significant interactions with layouts ($P < 0.05$) for 11 of 12 postures and 5 of 12 velocities, and with levels of precision ($P < 0.05$) for 5 of 12 velocities. With such important interaction effects, it is clear that breaking repetitive precision tasks into distinct phases promotes a better understanding of how precision work affects the musculoskeletal stress of the upper extremities. Graphical representations also show differences in how joint velocities were impacted by levels of precision for the forward and side layouts.

INTRODUCTION

Musculoskeletal disorders of the upper extremities are typically associated with workers' use of non-neutral postures, task repetitiveness, and several psychosocial and individual factors (Ekberg, Karlsson, and Axelson 1995, Jonsson, Persson and Kilbom, 1988).

Precision work has been shown to impose physical demands over and above similar work that does not require precision. There is evidence of higher muscle activity in such work than in non-precision work, performed in the same postures (Milerad and Ericson, 1994, Sporrong, Palmerud, Kadefors, and Herberts, 1998).

Movement to a precision target can be divided into two or more components. The first component is a ballistic component, performed rapidly with minimal need for visual feedback, where the operator moves from a starting position to the vicinity of a target. Successive components are more finely tuned, and require visual feedback for 'homing in' on the target (Welford, 1968). Hoffmann (1981) extended the familiar Fitts' Law to describe multi-component movements, where movement time in a task is the sum of times required to make each component of the movement. For example, a task where pins are inserted into holes can be described by two movement components;

$$MT = a + b * \log_2\left(\frac{2A}{W}\right) \pm c * \log_2\left(\frac{W}{(W-d)}\right)$$ where

MT is the movement time, A is the distance between the starting point and the hole, W is the width of the hole, d is the of the pin, and a, b, and c are constants (Hoffmann, 1981). Here, the first term represents the ballistic phase, and the second is homing-in. An index of difficulty, ID, is defined here as $ID = \log_2\left(\frac{2A}{W}\right)$.

Tasks which involve movement to precision targets, place stress on the upper extremities during all phases of the movement, with those produced during the ballistic phase likely to be very different than those produced during the homing in phase. During the ballistic movement, the loading at the shoulder depends on the posture (the extent of flexion or abduction) and the velocity and acceleration of the whole arm. Subsequent movements are slower and more finely tuned so that stresses at the shoulder girdle are likely to arise from a need to stabilize the extremities during work (Sporrong et. al., 1998).

Research that has attempted to evaluate the effect of precision on the upper extremities has either considered the precision component independently from the ballistic component of the movement (Sporrong et. al., 1998) or has measured postures and velocities of segments, or electromyography of muscles across both the ballistic and precision phases (Laursen et. al., 1998, Milerad and Ericson,

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012

1994). Yet, a better understanding of precision, and its impact on the musculoskeletal structures, might depend on understanding on what happens during the individual phases of the movements.

Hui and Hoffmann (2002) explored the affect of movements in different planes on repetitive precision tasks. They found that when movements are made in the sagittal plane, the whole arm is used. If a movement is sideward, the forearm is primarily responsible for the movement.

If task factors, other than precision, are important in tasks involving precision, an understanding of their nature may provide insights about how ergonomists can mitigate the deleterious effects of precision.

This paper describes a study that broke repetitive precision tasks into ballistic and homing in phases to measure the differences between the phases. During all trials, participants repetitively tapped, between a Home disk and a target disk on a horizontal plane, using a 1.50 mm diameter probe. A task cycle included tapping the Home, travel from the Home to the target disk, tapping the target, and travel back to the Home. The effects of different levels of precision, together with task layout (forward versus side) and task phase (ballistic versus homing-in) were evaluated.

It was hypothesized that:

- The postures, and joint velocities that occur during the ballistic phase are different from those that occur while homing-in. Subdivision of repetitive precision tasks into ballistic and homing in phases makes it possible to evaluate these differences.
- Movements made in different planes use different arm components, so that the use of different task layouts would result in different upper extremity musculoskeletal stresses.
- Tasks requiring high precision require different patterns of movement by the arm and hand than those of low precision.

METHODS

A full factorial, within subjects, design was used. The manipulated variables were layout and precision, with two levels of task layout and three levels of precision. The two levels of task layout were the 'side' layout and the 'forward' layout. For the 'side' layout, the target disk was placed to the participant's dominant side, at 30° with respect to the frontal plane. For the 'forward' layout the target disk was placed directly in front of the Home disk The three levels of precision were manipulated by changing the size of targets. The target was 3.20 mm in diameter for the high precision condition, 10.0 mm for the medium precision condition, and 19.0 mm for the low precision condition. The Home disk was always 19.0 mm in diameter. The phase of movement, ballistic or homing-in became a third within-subjects independent variable in subsequent analyses.

The center of the Home disk was aligned with the participant's centerline and approximately 10 mm from the table's front edge. The participant then stretched the dominant arm forward without extending the shoulder and with the forearm at neural pronation/ supination so that the smallest finger of the hand lay on the table. The center of the target disk was placed at the center of the participant's palm. Averaged over all participants, the mean center-to-center distance between the two disks was 190 mm, with a range of 150 to 243 mm. The IDs for the three different levels of precision averaged 4.32 for low precision (range 3.98 – 4.68), 5.25 for medium precision (range 4.91 – 5.60), and 6.89 for high precision (range 6.55 – 7.24).

There were twenty-four dependent variables measured throughout the tasks. These included 12 measures of wrist and forearm postures and 12 measures of joint velocities. Posture variables included; the 90th, 50th, and 10th percentile values, and the difference between the 90th and 10th percentile values of radial ulnar deviation (ru_90, ru_50, ru_10, and ru_spread), flexion/ extension (fe_90, fe_50, fe_10, and fe_spread), and pronation/ supination (ps_90, ps_50, ps_10, and ps_spread). Joint velocities included; the 95th, 75th, 25th, and 5th percentiles of radial/ ulnar velocity (ru_vel_95, ru_vel_75, ru_vel_25, and ru_vel_05), flexion/ extension velocity, and pronation/ supination velocity..

Fourteen right handed university students, ten females and four males, were participants. The height of a backless and armless chair was set to each participant's popliteal height and a table adjusted to 25 – 75 mm below the seated elbow height. The distance between the Home and target disks was normalized for each participant's reach distance, as described earlier. The chair was placed on top of a mat to inhibit its movement during the tasks.

Participants were fitted with a Biometrics XM 65 goniometer and XM 110 torsiometer. The voltage output was calibrated against known wrist angles with the aid of a calibration frame that had been designed after the one fashioned by Bucholtz and Wellman (1997). The goniometers were calibrated with the forearm rotated to 45° pronation since previous researchers had shown that the twist in the goniometer's wire that arose with pronation influenced the voltage output from the goniometer (Bucholtz and Wellman, 1997). Our pilot studies showed that forearm pronation was typically 30° - 60° during the repetitive precision tasks.

A training session had been designed to minimize the variability in performance that had been observed in untrained participants during pilot testing. The training session consisted of three 90 second, high precision forward movement trials and three 90 second high precision side movement trials.

All participants performed the tapping tasks in all six conditions (3 levels of precision and 2 levels of layout) for 60 seconds each. Experimental trials were performed in blocks, with either the block of forward movements or side movements performed first. Within each block, levels of precision were presented in random order. There were 90 seconds of rest between the end of each trial and the start of the next trial.

Wrist flexion/ extension, radial/ ulnar deviation, and forearm pronation/ supination were monitored with the goniometers and torsiometers at 100 Hertz during the tasks. Other software recorded when the Home and target disks were

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012

tapped and for how long. This information was synchronized with the data on wrist angles. A camera was set perpendicular to the movement and zoomed in on the work, so that the trajectory of the tool was recorded.

ANALYSIS

Cycle times were calculated from the original data. Statistical process control analyses were performed on these cycle times, to find a span of sixteen cycles (and the corresponding times for each condition) when participants exhibited little variability in performance.

Videos of the probe's trajectory were analyzed frame by frame to determine the length of the ballistic phases (for the portion of the tasks when participants moved from the Home to the target) for each participant in each condition. The ballistic phase occurred when the tool moved at more that 30 cm per second. This tool tip velocity was chosen after analyzing several videos made during pilot tests.

The data collected during calibration of the goniometer and torsiometer was regressed to determine the linear relationship between voltages and angles. The median correlation coefficients from these regressions was 0.966 for radial ulnar deviation, 0.991 for flexion extension, and 0.996 for pronation/ supination. The data from the goniometers was then passed through a fourth order Butterworth digital filter to eliminate electronic noise, and the filtered counts converted to wrist and forearm angles The forward difference technique was used to compute joint velocities from the angles. Data collected during the sixteen cycles where the movement was most regular was retained. The data was divided into files representing the ballistic and homing-in portions of the tasks.

The 90^{th}, 50^{th}, and 10^{th} percentile angles, and the difference between the 90^{th} percentile and 10^{th} percentile points, were calculated for radial/ ulnar deviation, flexion/ extension, and pronation/ supination for the homing in phase and the ballistic phase for each block of four cycles, from the sixteen task cycles when the movement was regular. The spreads, ru_spread, fe_spread, and ps_spread, were the differences between the 90^{th} percentile and the 10^{th} percentile values for each joint angle. The 95^{th}, 75^{th}, 25^{th}, and 5^{th} percentile values of the joint velocities were calculated. ANOVAs, with independent variables of task layout (forward or side), precision (high, medium, or low), and phase (ballistic or homing in), and person (participant ID) were performed on the percentile data.

RESULTS

Ballistic Versus Homing-in Contrasts

All 12 measures of wrist and forearm postures (Table 1) and 9 of the 12 joint velocities (Table 2) were significantly different during the ballistic and homing in phases ($P < 0.05$).

A graphical representation (Figure 1) shows the temporal pattern of movement for the entire task. During the ballistic phase, postures changed rapidly. During the homing-in phase, postures were sustained. The significantly smaller "spreads" during homing-in (Table 1) is another indicator that this happened.

Effects of Forward Versus Side Layouts

Results also emphasized the differences between arm movements that were made in the forward versus side directions. Four of the nine absolute measures of joint angles, and all three "spreads" were statistically different ($P < 0.05$) for the two layouts.(Table 1). The interaction between task phase and layout was significant for all nine absolute postures and for ru_spread and for fe_spread ($P < 0.050$) and nearly significant for ps_spread ($P = 0.07$).

Forearm postures were more non-neutral during homing-in than during the ballistic phase for both the forward and side layouts. For the forward movement, radial deviations were more extreme during the ballistic phases than during homing-in. For the side movement, radial deviation changed little between the ballistic and homing-in phases (Table 1).

Joint velocities were different during the forward and side movements ($P < 0.05$) for 10 of the 12 velocities (Table 2). Interactions between layout and task phase were significant ($P < 0.05$) for 5 of these 12 velocities.

Effects of Precision

Five of the twelve joint velocities were significantly different for different levels of task precision, with $P < 0.05$, (Table 2). There were statistically significant interactions between levels of precision and phase of movement for 5 of 12 joint velocities ($P < 0.05$). The only posture variable that was statistically different for different levels of precision was ru_spread ($P < 0.001$).

The pronation/ supination velocities differed for different levels of precision. These velocities were higher during the ballistic than the homing-in phases and higher during the forward than during the side movements. For the 75^{th} percentile pronation velocity (Figure 2), as the level of precision increased, the pronation velocity decreased during homing-in. This trend was not observed for ps_vel_75 during the ballistic phase. The effect is more pronounced for the forward than for the side layout.

DISCUSSION

Information about the probe's trajectory defined the end of the ballistic and the beginning of the homing-in phases of repetitive tasks. Wrist and forearm postures, and the rate at which they changed, were very different during the two phases, and it is expected that upper extremity biomechanical stresses were different as well. Partitioning such tasks into phases may lead to a better understanding of such stresses.

Wrist and forearm postures and joint velocities were also different for different task layouts. The effect of layout, however, is modified by the phase of movement (ballistic versus homing in). Therefore, understanding how different task layouts either mitigate or exacerbate muscuuloskeletal stresses, may require that the data taken during the ballistic and homing-in phases, be differentiated.

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012

Some wrist and forearm joint velocities were also impacted by precision levels. Statistical analyses also showed that the effects of precision are different for the different task phases, giving further impetus for isolating the ballistic and homing-in phases for such tasks. Graphical representation of the effect of phase of movement, task layout, and precision levels on some joint velocities, suggested that precision acts differently to impact joint velocities for the forward and side layouts. However, in this study, these effects do not reach statistical significance.

CONCLUSIONS

This research showed that differences between the ballistic and homing-in phases of repetitive precision tasks produced different movement patterns during the two phases. Some joint velocities also depended on task precision and on task layout. These main effects of precision and layout each interacted significantly with the phase of movement. The presence of such interactions justifies separating the data obtained during the two phases for analytical purposes.

There is some evidence that the effect of precision may be different for different task layouts. This result may be of practical importance. An understanding of how precision acts alone and together with other task factors, provides insights about how best to mitigate the deleterious effects of precision.

Our group is continuing research to investigate the effect of precision on upper extremity musculoskeletal stress.

ACKNOWLEDGEMENTS

This work was supported, in part, by a grant awarded by the National Institute for Occupational Safety and Health (Grant #1-R03-OH07532-01).

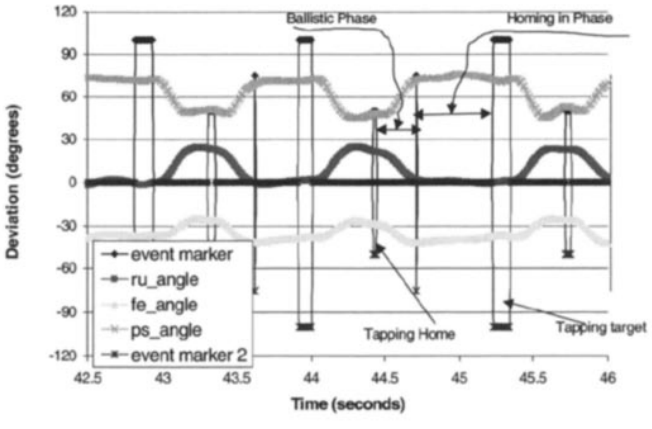

Figure 1. Temporal representation of repetitive precision task

REFERENCES

Buchholz, B., and Wellman, H. (1997) . Practical application of a biaxial goniometer to the wrist joint. Proceedings of the Human Factors and Ergonomics Society. Human Factors and Ergonomics Society, 39, 119-129.

Ekberg, K., Karlsson, M., and Axelson, O. (1995) . Cross-sectional study of risk factors for symptoms in the neck and shoulder area. Ergonomics, 38, 971-980.

Hoffmann, E.R. (1981) . An ergonomics approach to predetermined motion time systems. Proceedings, Institute of Industrial Engineers, Ninth International Conference, Australia, 30-47.

Hui, M.C., and Hoffmann, E.R. (2002) . Ballistic movement times of different arm components. (in press)

Jonsson, B.G., Persson, J., and Kilbom, A. (1988) . Disorders of the cervicobrachial region among female workers in the electronics industry: A two-year follow up. International Journal of Industrial Ergonomics, 3, 1-12.

Laursen, B., Jensen, B.R., and Sjogaard, G. (1998) . Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. European Journal of Applied Physiology & Occupational Physiology, 78, 544-548.

Milerad, E., and Ericson, M. (1994) . Effects of precision and force demands, grip diameter, and arm support during manual work; an electromyographic study. Ergonomics, 30, 255-264.

Sporrong, H., Palmerud, G., Kadefors, R., and Herberts, P. (1998) . The effect of light manual precision work on shoulder muscles—an EMG analysis. Journal of Electromyography & Kinesiology, 8, 177-184.

Welford, A.T. (1968) . Fundamentals of Skill. London: Metheun and Co., Ltd.

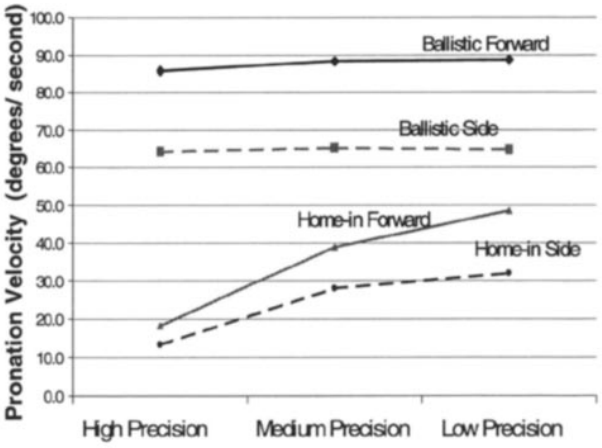

Figure 2. The effect of precision, phase of movement, and layout on 75th percentile pronation velocity (ps_vel_75).

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012

Table 1
The Effect of Phase of Movement, Layout, and Precision on Wrist and Forearm Postures

	Mean Postures				P-values				
	Ballistic forward	Ballistic side	Homing-in forward	Homing-in side	Forward vs. Side (F/S)	Ballistic versus Homing in (B/H)	interaction (F/S)*(B/H)	Precision (P)	interaction (P)*(B/H)
ru_90	17.1	16.5	9	16.5	0.244	0.003 *	0.001 *	0.433	0.935
ru_50	12.6	14.1	6.4	14.2	0.106	0.012 *	0.002 *	0.603	0.902
ru_10	6.9	11.9	3.5	12.1	0.014 *	0.049 *	0.008 *	0.885	0.845
fe_90	-34.3	-47.7	-50.6	-51.3	0.030 *	< 0.001 *	< 0.001 *	0.416	0.112
fe_50	-41.9	-50.8	-53.4	-53.3	0.101	< 0.001 *	< 0.001 *	0.476	0.805
fe_10	-51.5	-53.9	-56.2	-55.5	0.680	< 0.001 *	< 0.001 *	0.437	0.865
ps_90	63.8	69.6	72.3	75	0.103	< 0.001 *	< 0.001 *	0.722	0.041 *
ps_50	53.9	62.6	68.9	72.2	0.031 *	< 0.001 *	0.002 *	0.811	0.492
ps_10	48.8	58.3	64.9	69	0.020 *	< 0.001 *	< 0.001 *	0.756	0.716
ru_spread	10.1	4.5	4.3	4.3	< 0.001 *	< 0.001 *	0.002 *	< 0.001 *	0.956
fe_spread	17.2	5.7	6.3	4.2	< 0.001 *	< 0.001 *	< 0.001 *	0.568	0.058 **
ps_spread	15	7.3	11.2	5.9	0.003*	0.001 *	0.066 **	0.365	0.852

Note 1: Postures are in degrees. Positive values represent ulnar deviation, wrist flexion, and forearm pronation.
Note 2: * refers to results that are statistically significant ($P < 0.050$).
** refers to results that are nearly significant ($0.050 \leq P \leq 0.100$)

Table 2
The Effect of Phase of Movement, Layout, and Precision on Wrist and Forearm Joint Velocities

	P-values				
Variable	(B/H))	(F/S)	(B/H) * (F*S)	(P)	(B/H) * (P)
ru_vel_95	0.957	0.185	0.437	0.088 **	0.658
ru_vel_75	0.530	0.025 *	0.516	0.039 *	0.883
ru_vel_25	< 0.001 *	0.003 *	0.054 **	0.717	0.009 *
ru_vel_05	< 0.001 *	0.002 *	0.112	0.638	0.012 *
fe_vel_95	0.052 *	0.322	0.759	0.376	0.516
fe_vel_75	< 0.001 *	< 0.001 *	0.009 *	0.177	0.162
fe_vel_25	< 0.001 *	< 0.001 *	< 0.001 *	0.513	0.212
fe_vel_05	< 0.001 *	< 0.001 *	< 0.001 *	0.852	0.562
ps_vel_95	< 0.001 *	0.009 *	0.196	0.020 *	0.023 *
ps_vel_75	0.003 *	0.005 *	0.268	< 0.001 *	0.005 *
ps_vel_25	< 0.001 *	< 0.001 *	0.935	< 0.001 *	0.023 *
ps_vel_05	< 0.001 *	0.036 *	0.438	< 0.001 *	0.120

Note 1 * refers to results that are statistically significant ($P < 0.050$).
** refers to results that are nearly significant ($0.050 \leq P \leq 0.100$).

Downloaded from pro.sagepub.com at CDC Public Health Library & Information Center on December 18, 2012