

WRIST AND FOREARM MOVEMENTS WHILE HOMING IN ON PRECISION TARGETS

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To determine whether people employed different movement strategies when they homed in on precision targets during repetitive tapping tasks, homing in movements were isolated for analysis. The time required to home in on the targets and the absolute magnitudes of peaks in joint velocities during homing in were calculated. In addition, the number of times that three types of corrective actions: changes in movement direction, inflections in velocity, and peaks in velocity, were made during pronation/ supination and in radial/ ulnar actions were counted.

The number of times each type of corrective action was made was regressed against the time required for homing in. The relationships were highly linear, with correlation coefficients between 0.78 and 0.94. The implication was that corrective actions occurred at a similar mean frequency, regardless of the level of task precision and that homing in was a very active process at all levels of precision studied. The number of times any type of corrective action was taken increased significantly with increased precision ($P < 0.001$).

The mean absolute magnitudes of pronation/ supination and radial/ ulnar velocities declined significantly with increased task precision ($P < 0.001$). However, the fact that the number of corrective actions increased with increased task precision showed that the movements toward the high precision targets were not just 'slowed down' versions of the movements to the low precision targets.

Differences between the number of corrective actions, and the magnitudes of peak velocities for tasks of different levels of precision reflect different biomechanical stresses at the wrist and forearm for the different tasks. These differences are expected to result in different effects on shoulder muscles at different levels of precision.

INTRODUCTION

Precision demands have been associated with an increased frequency of neck and shoulder disorders (Milerad and Ekenvall, 1990) and work related myalgia (Hagg, 2000). Experimental studies have shown that musculoskeletal stress, as measured by the increased amplitude of the electromyographic signal (EMG), increased with increased precision (Milerad and Ericson, 1994, Shyhalla, 2002), and that the EMG from shoulder muscles was higher when manipulative hand work was performed than when the hands were relaxed and the same shoulder and elbow postures were sustained (Sporrong et. al., 1998).

Stresses on shoulder muscles are not likely to be the same through the entire movement to a precision target. Such a movement can be modeled as an initial rapid movement, where visual feedback is not required, followed by a slower homing in component. The duration of the initial rapid movement depends only on the amplitude of that movement, while the duration of the slower homing in component depends on the size of the target (Gan and Hoffmann, 1988). Homing in movements have a prolonged final deceleration which

consisted of multiple movements that are adjustments to the movement's trajectory (Welford, 1968).

During tasks, Shyhalla's (2002) participants sat at a table and repetitively tapped between a Home disk, which was approximately 50 mm from the table edge, and a target disk, which was approximately 190 mm from the Home. In order to learn more about how repetitive precision tasks contribute to musculoskeletal stress, the Home to target movements were divided into a rapid distance covering movement and a slower homing in component (Shyhalla, 2002, Shyhalla et. al., 2002).

The velocity trajectory of the probe used to strike the disks was analyzed to differentiate the two components of the movement (Shyhalla, 2002, Shyhalla et. al., 2002). The initial rapid movement was characterized by a rapid increase, and then an initially rapid decline in the probe's velocity. Then, the velocity passed through an inflection. The homing in movement was considered to be initiated at the point of inflection. 'Probe transition time' was taken as the time between when the probe left the Home and when the probe's velocity dropped below 0.30 m/s, which was the usual velocity at the inflection (Shyhalla, 2002).

Additional data showed that, when the probe's velocity changed, there was a synchronous change in the pronation/ supination, wrist flexion/ extension, and wrist radial/ ulnar movements of the arm used to guide the probe (Shyhalla, 2002, Shyhalla et. al., 2002). This result showed that multiple joints and muscle groups were coordinated in the movement.

The trajectory of pronation/ supination during the Home to target movement was studied. This joint rapidly accelerated to a maximum velocity, rapidly decelerated, and then passed through an inflection in velocity. The transition from the rapid distance covering movement to the slower homing in component was said to occur at the point of inflection. The duration of the distance covering movement, 'Forearm inflection time', was taken to be the time between when the probe left the Home and when the forearm passed through the inflection. The two measures for the duration of the distance covering phase were regressed to give: Probe transition time = $0.72 * \text{Forearm inflection time} + 0.11$ ($r = 0.77$). The mean square error was 0.03 seconds, and was well within the temporal resolution of the camera, which was 0.07 seconds. Therefore, the transition in velocity of the probe, and the point of inflection in pronation/ supination velocity were taken as equivalent indices of the transition from the distance covering and the homing in components of movement. ANOVAs showed that there was no statistically significant difference in either 'Probe transition time' or in 'Forearm inflection time' for different levels of precision ($P < 0.001$).

The work described here extends the work by Shyhalla et. al. (2002), which showed that the effect of precision on joint velocities during the Home to target movement was much more pronounced during homing in than during the distance covering portion of the movement. Welford's (1968) work described homing in as consisting of small movements of a probe, that were attempts to correct for differences between the position of the probe and the target. The analysis described here further characterizes homing in as corrective actions in pronation/ supination and radial/ ulnar movements.

The current work hypothesizes that:

- With increases in precision, there will be more corrections in the movement of the forearm during homing in.
- Differences in precision will elicit differences in the movement strategies employed during homing in.

Corrections, in this work, are defined as changes in the direction of movement or changes in the rate of movement. If one overshoots a target, a correction would entail a reversal in the original direction of the

movement, so that a wrist or forearm that was previously moving clockwise will change and move counterclockwise (or vice-versa). Such corrective actions are referred to as *ru_vel_cross* for radial/ ulnar movement, and *ps_vel_cross* for pronation/ supination movements. Corrections in the rate of movement were defined by inflections in velocity (which were also peaks in acceleration) and by peaks in the velocity of radial/ ulnar and pronation/ supination trajectories. These parameters are referred to as *ru_vel_infl*, *ps_vel_infl*, *ru_vel_peak*, and *ps_vel_peak* in this report.

METHODS

During the experiment, 16 participants (6 males) repetitively tapped between a Home disk and a target disk. The participants were all right handed university students who were free of musculoskeletal disorders. A task cycle consisted of tapping the Home, travel from the Home to the target disk, tapping the target, and travel back to the Home. A full factorial within subjects design, with two levels of task layout and three levels of precision, was used. 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, to elicit movement in the scapular plane. For the 'forward' layout, the target was placed directly in front of the Home.

The Fitts difficulty indices for the tasks was

$$ID = \log_2 \left(\frac{2A}{W} \right),$$

where A was the average reach

distance for the 16 participants (190 mm) and W was the diameter of the target. ID values were 6.89 for the high precision (3.20 mm diameter target), 5.25 for the medium precision (10.0 mm diameter target) and 4.32 for the low precision (19.0 mm diameter target) conditions.

Participants underwent training to minimize the variability in performance that had been observed in untrained participants during pilot testing. Training consisted of three 90-second long, high precision forward movement trials and three 90-second long, high precision side movement trials. Participants worked in all six conditions for 60 seconds per condition, and had 90 seconds of rest after each trial. 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.

Joint movements were monitored continuously at 100 Hertz with a Biometrics XM 65 goniometer, measuring wrist flexion/ extension and radial/ ulnar

deviation, and a XM 110 torsionmeter, measuring forearm pronation/ supination. These had been calibrated against known joint angles for each participant. The times when the Home and target disks were tapped were continuously integrated with the goniometer data.

ANALYSIS

The data collected during calibration of the goniometer and torsionmeter were regressed to determine the linear relationship between voltages and angles. The data from the goniometers were then passed through a fourth order Butterworth digital filter to eliminate electronic noise, and the filtered voltages converted to wrist and forearm angles. The forward difference technique was used to compute joint velocities and accelerations from the angles.

A Visual Basic routine made calculations during nine task cycles for each participant and experimental condition. The program first calculated the duration of homing in (Home in_time) as the difference between the time when the forearm passed through the inflection point and when the probe reached the target. The number of corrective actions that were made during homing in for the same nine cycles were counted. Counts were made of:

1. The times per cycle that participants made changes in movement direction, from clockwise to counterclockwise movements and counterclockwise to clockwise radial/ ulnar (ru_vel_cross) and pronation/ supination (ps_vel_cross) movements.
2. The times per cycle that inflections in radial/ ulnar (ru_vel_infl) and pronation/ supination (ps_vel_infl) velocities occurred.
3. The number of peaks in joint velocity. These parameters were ru_vel_peak and ps_vel_peak.

In addition, the average absolute magnitudes of peaks in velocity in radial/ ulnar deviation (sze_ru_vel_peak) and in pronation/ supination (sze_ps_vel_peak) were computed for each task cycle.

MANOVA analysis¹ was performed, with the independent variables of participant and precision, and the dependent variables: Home in_time, ru_vel_cross, ps_vel_cross, ru_vel_infl, ps_vel_infl, ps_vel_peak, and ru_vel_peak.

The variables: ru_vel_cross, ps_vel_cross, ru_vel_infl, ps_vel_infl, ru_vel_peak, and ps_vel_peak from all participants and all levels of precision, were

each regressed against the time required for homing in. A Factor Analysis was performed on the six measures of corrective movements.

ANOVA analyses, for cycles when peaks in velocities or accelerations were present, were performed for the independent variables of person and precision, and the dependent variables, sze_ru_vel_peak and sze_ps_vel_peak.

RESULTS

The results showed that the time to complete the homing in movement component was dependent on the level of precision ($P < 0.001$). That average time increased from 0.19 seconds for the low precision tasks to 0.55 seconds for the high precision tasks (Table 1).

All six parameters that reflected changes in movement direction, or in the rate of movement, were highly sensitive to precision ($P < 0.001$) (Table 1). People changed both their direction of movement (ru_vel_cross and ps_vel_cross) and rate of movement (ru_vel_infl, ps_vel_infl, ru_vel_peak and ps_vel_peak) more times during homing in as the level of precision increased ($P < 0.001$). Peak velocities decreased with increasing precision ($P < 0.001$) (Table 1).

Regressions of any of the corrective parameters: ru_vel_cross, ps_vel_cross, ru_vel_infl, ps_vel_infl, ru_vel_peak, and ps_vel_peak against Home in_time showed that the number of any of these types of corrections was lineally related to the time necessary for homing in. Correlation coefficients ranged from 0.95 for ps_vel_infl versus Home in_time (Figure 1a) to 0.78 for ru_vel_cross versus Home in_time (Figure 1b). Corrective movements were made often; at mean frequencies of 0.08 seconds for ps_vel_cross, 0.09 seconds for ru_vel_cross, 0.06 seconds for ru_vel_infl and ps_vel_infl, and at 0.06 seconds for ru_vel_peak and ps_vel_peak.

Factor analysis, without rotation, was performed on the six parameters: ru_vel_cross, ps_vel_cross, ru_vel_infl, ps_vel_infl, ru_vel_peak, and ps_vel_peak. A single factor, Move_correct, accounted for 81.3% of the variance in the six parameters.

DISCUSSION

The analyses showed that homing in was a highly active process, with numerous corrections in the direction of movement (ru_vel_cross and ps_vel_cross) and in the rate of movement (ru_vel_infl, ps_vel_infl, ru_vel_peak, and ps_vel_peak). The first hypothesis, that the number of corrective actions would increase with increased task precision ($P < 0.001$) was supported by the MANOVA analysis.

¹ For the analysis, only 801 task cycles were analyzed. 37 of the 838 task cycles did not show transitions from a rapid distance covering movement to a slower homing in movement.

This work also reveals some interesting features about human movement. The transition in the velocity of the probe, and a point of inflection in the velocity of the forearm, occurred simultaneously. In other words, either indicator could be used to differentiate the distance covering and the homing in portions of the Home to target movement.

The factor analysis also revealed that corrective actions by the forearm and the radial/ ulnar joint were related during homing in, suggesting that these individual actions might be controlled via a common mechanism.

Decreases in the absolute magnitudes of peak velocities with increases in precision implied that homing in on high precision targets is, on average, performed more slowly than homing in on low precision targets. The slower movement, coupled with the greater number of corrective actions necessary with higher levels of task precision, showed that different movement strategies were employed during homing in with different levels of task precision. Therefore, the second hypothesis was supported.

It is likely that the different strategies employed when homing in on high versus low precision targets would result in biomechanical differences at the shoulder for the different tasks. Radial/ ulnar movements, for example, are accompanied by time-varying reaction joint forces at the wrist. Link segment modeling, as described by Winter (1990), predicts that these forces would impact the more proximal joints, including shoulder joints. Differences in the activation patterns of shoulder muscles can be expected to accommodate for such differences.

Fuller analysis of the wrist and forearm trajectories can be performed on the existing data to determine how torques at the joints and many other biomechanical factors change with task precision. Simple biomechanical analyses, however, will not explain what is happening to individual shoulder muscles, which are part of a complex agonistic-antagonistic system. Changes in EMG for any shoulder muscle will be likely to impact, but not necessarily parallel changes in other muscles, as these muscles can redistribute loads. Palmerud et al. (1998) showed that when the trapezius was deliberately relaxed, its EMG decreased by 60% – 70%. Meanwhile, the EMG of the major rhomboid, minor rhomboid, and transverse trapezius approximately doubled in magnitude.

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Table 1
Effect of Precision on Homing in Time, Number of Changes in Movement, and in Peak Velocities During Homing in

Parameter	High Precision	Medium Precision	Low Precision
Home in_time	0.55	0.28	0.19
ru_vel_cross	3.80	1.51	0.69
ps_vel_cross	3.51	1.40	0.77
ru_vel_infl	8.83	3.70	2.26
ps_vel_infl	9.66	4.29	2.79
ru_vel_peak	6.42	2.81	1.71
ps_vel_peak	6.23	2.97	1.78
sze_ru_vel_peak	13.11	15.51	23.76
sze_ps_vel_peak	15.28	25.39	28.81

Note 1. The units of ps_vel_cross, ru_vel_cross, ps_vel_infl, ru_vel_infl, ps_vel_peak, and ru_vel_peak are the number of each type of corrective action during homing in. Home in_time is in seconds. Sze_ru_vel_peak and sze_ps_vel_peak are in degrees per second.

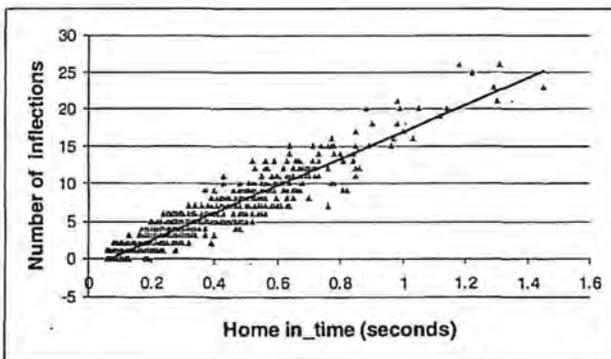


Figure 1a. Inflections in pronation/ supination velocity during homing in. The regression gives: $ps_vel_infl = 18.15 (\text{Home in_time}) - 1.23$ ($r = 0.95$).

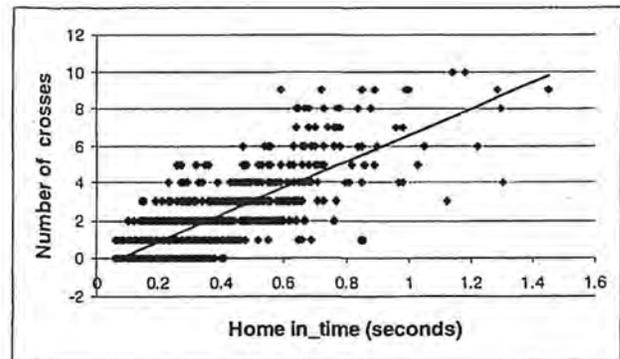


Figure 1b. Zero crossings in radial/ ulnar velocity during homing in. The regression gives: $ru_vel_cross = 7.11 (\text{Home in_time}) - 0.52$ ($r = 0.78$).