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Hand-hold location and trunk kinematics during box handling

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Abstract

Trunk kinematics variables have been shown to be related to low back injury risk during lifting tasks and it was hypothesized that changes in hand-hold positions could influence trunk kinematics and thereby risk. Fourteen subjects lifted a 5 or 10kg box using four different hand placement locations (two symmetric and two asymmetric) while their trunk kinematics (position, velocity and acceleration in the sagittal, coronal and transverse planes) were captured using the lumbar motion monitor (LMM). These kinematics data were then used to calculate the Probability of High Risk Group Membership (PHRGM) as defined in the LMM risk assessment model. The results showed significant effects of hand placement on trunk kinematics resulting in significant changes in the PHRGM variable- ranging from a low of 20% in a the symmetric low load condition to a high of 38% under the asymmetric, 10kg condition.

Relevance of the findings for ergonomics research and practice:

Manual materials handlers use a variety of hand-hold positions on boxes during lifting. Where a lifter grabs the box can influence the trunk kinematics during the lifting task and these kinematics have been shown to provide some insight into risk of low back injury. This study documents the trunk postures and kinematics as a function of hand-hold position.

Keywords: Hand Placement, Manual Materials Handling, Trunk Kinematics, Lumbar Motion Monitor

1. Introduction

Low back injuries remain a significant challenge in many industries. Bernard *et al.* (1997) performed an analysis of data from the Bureau of Labor Statistics and found that 32% of all workplace injuries and illnesses that involved days away from work were the result of repetitive motion or overexertion and 52% of these cases involved an overexertion in lifting. For this reason, many occupational biomechanics studies and biomechanics models have focused on finding the causes of these injuries and complaints as well as a means to control them (Chaffin 2009, Kuijer *et al*. 2005, Garg and Kapellusch, 2009). For instance, with an aim to reduce the incidence and severity of work-related low back disorders, ergonomics researchers have studied lifting strategies (e.g. Dempsey 2003; Burgess-Limerick 2003, Kingma *et al.* 1998, Kingma *et al.* 2004) with some having a particular focus on the effects of load coupling (Mirka *et al.* 1998, Gagnon *et al.* 2000). In a study of industrial manual materials handlers, Drury *et al.* (1982) documented the self-selected hand positioning as these workers performed various lifting tasks. They used an industrial survey to collect data on hand position and investigated the effects of subject, box and task variables on hand position. These data were collected for 27 participants across nine factories. They found that the most common hand placement was where one hand gripped the upper front corner of the box and the other the lower rear corner and noted that this provided “horizontal and vertical stabilization” (p. 553). Another common hand placement, particularly for heavy box handling, was where the hands gripped at the right and left handles (if they existed) or bottom edges in the middle of the box (Drury and Pizatella 1983). These authors concluded by noting that the choice of hand position is very much influenced by many task variables (lifting vs. lowering, load mass, presence of handles, etc.) Finally, it should also be noted that previous research has shown that even experienced handlers do not generally agree on the best methods of lifting (Authier and Lortie 1993).

As one considers the risks posed by manual materials handling tasks, an important aspect of these tasks is the trunk kinematics strategy employed by the lifter. In a study of 403 manual materials handlers spanning 48 manufacturing companies, Marras *et al.* (1993) showed a relationship between five job-related characteristics and the probability that these jobs would be considered high risk for low back injury. These characteristics included both job-determined characteristics (lift rate and maximum moment) as well as lifter-determined trunk kinematics (average twisting velocity, maximum sagittal flexion, and maximum lateral velocity). Using these data these researchers developed a risk assessment model (herein called the LMM model) that allows one to estimate the probability that a job in question belongs to the set of jobs considered high risk. One needs to capture the trunk kinematics used to perform the basic work, identify the values for each of the above five variables, and then compute this value of probability of high risk group membership (PHRGM).

Extending these findings to the topic of hand position during lifting, it is likely that hand positions, particularly left-right asymmetric hand positions, will influence relevant trunk kinematic variables during lifting. The objectives of this study are to quantify the effects of hand placement on trunk motion characteristics and to evaluate the effects of different hand positions on risk as assessed by the LMM model.

2. Methodology

2.1. Participants

Seven male and seven female volunteers from Iowa State University participated in this study. None had a history of chronic or current low-back pain or other musculoskeletal disorders.

Experience in materials handling varied but none were currently professional manual materials handlers. The basic anthropometry of the subject pool, Mean (±SD), was age 23.6 (± 3.7) years, height 173.3 (±8.3) cm and whole body mass 69.5 (±9.5) kg. All provided written informed consent before participation.

2.2. Apparatus

2.2.1 Data Collection Apparatus

The Lumbar Motion Monitor (LMM) (Chattanooga Group Inc., TN) was used to capture the three-dimensional trunk kinematics during the lifting task (Marras *et al.* 1992). The LMM provides data on angular position, velocity and acceleration in the sagittal, coronal and transverse plane. LMM data are collected at a rate of 60 Hz.

2.2.2 Study Design

The load lifted in this study was a 50 cm (width) x 40 cm (depth in line of the sagittal plane) x 24 cm (height) handle-less cardboard box that was filled with material so that the total mass was either 5 or 10 kg. Three wooden platforms were used to position the cardboard box at the different starting heights used. The surface of the platform was 63 cm wide by 50 cm deep and the box was centered on the platform. This configuration (surface wider and deeper than the box itself) did not allow the subjects to wrap their fingers under the box directly off of the platform. Participants were not allowed to tilt the box at the starting position. This meant that the subject had to begin the lift with a compression coupling technique.

2.3. Experimental Design

2.3.1. Independent Variables

In this study, there were three independent variables: There were four levels of hand PLACEMENT: (A) hands on the sides of the box at the bottom, (B) hands on the sides of the box at the top, (C) left hand on left upper proximal corner and right hand on the right lower distal corner of the box, and (D) left hand on left lower proximal corner and right hand on the right upper distal corner of the box (Figure 1). There were two levels of load MASS: 5 and 10 kg and three levels of load HEIGHT (representing the height of the platform on which the load rested): 30, 60 and 90 cm.

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Insert Figure 1 about here

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2.3.2. Dependent Variables

The dependent variables in this study were eight measures of trunk kinematics and a measure of injury risk. The trunk kinematics variables were: the peak coronal angle (PCA), peak sagittal angle (PSA), peak transverse angle (PTA), peak coronal velocity (PCV), mean transverse velocity (MTV), peak coronal acceleration (PCAC), peak sagittal acceleration (PSAC), peak transverse acceleration (PTAC) and probability of high risk group membership (PHRGM) from the LMM model. Each was found during the concentric range of the lifting motion.

2.4. Experimental Tasks

Upon arrival the participant was provided a brief overview of the experiment and was asked to sign the approved informed consent form. S/he then completed a short warm-up exercise designed to help prepare the body for the lifting task. The LMM was then secured to the torso and the participant moved to the lifting area. Prior to conducting the experimental trials, a brief familiarization period was provided so that the participant could become accustomed to the LMM and the lifting task. Participants were encouraged to lift the box using each of the hand positions: black (A), blue (B), green (C) and red (D) tape marked the hand positions for the participants (Figure 1.)

During the experimental trials, participants were asked to align their toes on a piece of tape 38 cm from the center of mass of the box. This was done to standardize the moment of the load about the spine. Participants were instructed to use a stoop lifting technique with feet shoulder width apart and were asked to lift the load from the platform up to elbow height and then return the load to the platform, at a rate of 2 lifts/per minute. No constraints were placed on coupling. Upon completion of the lift, the lab assistant changed the lifting configuration for the next trial. Subjects performed two lifts for each combination of PLACEMENT, HEIGHT, and MASS resulting in a total of 48 lifting tasks and a total lifting time of 24 minutes. The order of presentation of the conditions was completely randomized.

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Insert Figure 2 about here

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2.5. Data Processing

The concentric range of the lifting motion was determined from the angular data from the sagittal plane. The concentric phase began at the point of greatest sagittal flexion and ended when the participant returned to their upright posture. The peak angular values were simply the greatest deviation from zero observed in each of the three planes (PCA, PSA, PTA). The peak coronal velocity (PCV) and the peak transverse velocity (PTV) were the peak of the absolute values observed and the mean transverse angular velocity (MTV) was defined as the average of the absolute values of the angular velocity in the transverse plane. The peak coronal acceleration (PCAC) and the peak transverse acceleration (PTAC) were the peak of the absolute values of these variables, while the peak sagittal acceleration (PSAC) value was limited to the peak acceleration during the initiation of the concentric lifting motion.

2.6. LMM Model

The goal of using the LMM model was to calculate the probability of high risk group membership (PHRGM). Thus, for each trial for each subject, the above kinematics variables were input into regression equations that estimated an individual probability for each variable. For this purpose the lift rate was set at 2 lifts/minute and the maximum moment was either 27 Nm (for 5 kg) or 54 Nm (for 10 kg). The probability associated with each of these five variables was averaged to calculate the PHRGM for each trial.

2.6. Statistical Analysis

All statistical analyses in this study were conducted using SAS®. Prior to conducting the formal statistical analysis, diagnostic tests were performed on the data to ensure that none of the assumptions of the ANOVA procedure were violated. This included the test for homoscedasticity (Bartlett's Test and Levene's Test) and normality (Anderson-Darling Normality Test) (Montgomery 2001).

A repeated-measures multivariate analyses of variance (MANOVA) was performed for all the dependent variables. Univariate analysis of variance (ANOVAs) was conducted on all significant effects reported by MANOVA. For each dependent variable that generated a significant interaction as well as significant main effects a simple effect analysis was performed. The Tukey multiple pairwise comparison was performed on all significant main effects to further explore these effects. P-values of less than 0.05 were considered statistically significant in analyses in this experiment.

3. Results

The results from the MANOVA procedure indicated that PLACEMENT, MASS, HEIGHT, and PLACEMENT*HEIGHT were all significant (Table 1). Subsequent univariate ANOVA of the trunk kinematics variables showed significant effects of the interaction between PLACEMENT and HEIGHT for all dependent variables. Simple effects analysis on the main effects of HEIGHT and PLACEMENT found most of the dependent variables were significantly affected by the changes in the box height and hand placement variables (dependent measures not shown to be significant in the simple effects analysis are marked with a "*" in Table 1.). In general, hand positions A and C had the highest peak sagittal angle (Figure 2) and sagittal acceleration. These results coincide well with expectations given both the horizontal and vertical hand positioning required to reach the designated hand positions. Not as clear were the expectations with regard to the motions in the transverse and coronal planes. The results of this study show that hand positions C and D both generated greater maximum angles, peak velocities and peak accelerations (Figures 3 and 4) in both the transverse and coronal planes, indicating a sharing of the postural deviations between these two planes during the asymmetric hand position lifts.

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Insert Table 1 and Figures 2-4 about here

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Results of the ANOVA for the PHRGM variable provided some insight into the overall impact of these task variables on risk (Tables 1 and 2). Comparing specific conditions, Position B with 5kg mass lifted at the 90cm height yielded an average (across subjects) PHRGM value of just 20% while the position C with 10kg and 30cm height raised the average probability to 38% (Table 2.) Averaged across conditions the increase in PHRGM was about 3% when going from a symmetric hand position (A or B) to one of the diagonal hand positions (C or D). Figure 5 illustrates the interaction between PLACEMENT and HEIGHT.

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Insert Table 2 and Figure 5 about here

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4. Discussion

The principal goal of this study was to evaluate the effects of hand placement on trunk kinematics during lifting. The four hand positions chosen for this study account for approximately 64% of the hand positions observed in industry (Drury *et al.* 1982). Results showed that the interaction between hand placement and load height influenced all evaluated trunk motion variables and probability of high risk group membership, while load mass only affected the peak sagittal angular acceleration and the probability of high risk group membership. The interpretation of the effects of load mass on lifting kinematics and risk are fairly straight forward and consistent with previous research that showed as load mass increased, peak sagittal acceleration decreased (Mirka and Baker 1996). Likewise the increase in load moment would have a direct impact on the computed probability of high risk group membership from the LMM risk assessment model (Marras *et al.* 1993, Marras *et al.* 1995). Additionally, previous studies have shown that forward bending moment is sensitive to initial lifting height (Lavender *et al.* 2003, Hoozemans *et al.*2008). This might indicate that the B hand placement is preferred because of its decreased peak flexion angle due to higher initial hand placement in comparison with other hand placements.

The interpretation of the interaction effect between hand placement and load height and main effect of hand placement were less clear *a priori* and are worthy of further exploration. As one considers the multi-link system of the human lifter, the process of locating the hand in specific locations on the box and performing the lifting motion, can be accomplished through a variety of combinations of lumbar and upper extremity postures and motions. The results of the current study indicate that the postures chosen included trunk motions in all three cardinal planes of human motion. Averaged across box masses and lifting heights, the diagonal coupling postures (C and D) generated 35% higher values of peak coronal velocity and 24% higher values of peak transverse velocity resulting in an increase in the probability of high risk group membership. An interesting comparison between these results and those of Gagnon *et al.* (2000) can be made. In the Gagnon *et al.* (2000) the investigators had the participants lift a 12.4 kg box using the diagonal hand position strategy (Position D in the current study) and perform an asymmetric lifting task (box moved through 90º). In one of the conditions the participants were asked to keep their shoulders parallel with the ground while in another condition they were allowed to have their shoulders in a non-parallel configuration as the different hand positions would dictate. In their study they developed a 3D multisegment model that allowed them to calculate the peak 3D trunk moments and compare across conditions. They found that the parallel lifting configuration generated greater trunk extension moments than did the non-parallel configuration, but there was also a significant increase in the peak moment in the coronal plane with the non-parallel lifting strategy. This result might indicate that training to this "parallel lifting strategy" might be an effective method for reducing these coronal plane motions. While we did not control the trunk postures during the lifting motions in the current study, the results of increased coronal and transverse plane motions shown here, would increase risk and the biomechanical responses shown in Gagnon *et al.* (2000) can draw the link to the underlying biomechanical mechanism.

There are some limitations to the current study that should be noted. First, as was noted previously, there are some potential benefits from these “diagonal” hand position strategies that are not quantified in the current study (e.g. load stability). Specifically, Drury *et al.* (1982) commented that “A ‘good’ hand position should provide both horizontal and vertical stability, and these two diagonally opposite hand positions took this principle as far as possible.” (p. 563). This issue of load stability was not considered in the current study and therefore might attenuate some of the concerns related to trunk kinematics shown here. Another limitation is related to the single size of box used in the current study. Very much relevant to the discussion of transverse and coronal plane motions is the fact that the size of the box (length and width) used in the current study were near the 90th percentile of those seen in the Drury *et al.* (1982) study. The dimensions of the box could have a direct impact on the degree of transverse and coronal plan motions used because the postures of the upper extremity could moderate these low back motions. Future research may seek to explore the relationship between box size and the motions in the transverse and coronal plane as well as explore the tradeoffs between these motions and lifting stability.

5. Conclusions

This study quantified the effects of varied hand placement on trunk kinematics and a measure of low back injury risk. The hand placement locations used in this study were those found to be most often seen in industry and the results show that trunk kinematics variables are sensitive to changes in hand placement and the resulting estimate of risk using the LMM risk assessment model reflects this sensitivity. Of the conditions considered in the current study, the lowest risk (PHRGM 20%) was seen in the condition where the lifter grasped the top of the middle of the 5kg box and from the highest height (90cm). Conversely the highest risk (PHRGM 38%) was seen in the condition where the lifter had to reach to the low and furthest corner of the box with the right hand and the upper and nearest corner of the box with the left hand, with a box mass of 10kg and lift the box from the lowest height (30cm). This study has shown that hand position can have moderate effects on required trunk kinematics and should be considered when evaluating risk of lifting tasks.

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Table 1. MANOVA and Univariate ANOVA results.

Independent Variables	MANOVA	Peak Coronal Angle	Peak Sagittal Angle	Peak Transverse Angle	Peak Coronal Velocity	Mean Transverse Velocity	Peak Coronal Accel	Peak Sagittal Accel	Peak Transverse Accel	PHRGM
PLACEMENT (P)	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0012**	**<. 0001***	**<. 0001**	**<. 0001**
HEIGHT (H)	**<.0001**	**<. 0001**	**<. 0001**	**<. 0001***	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**
MASS(M)	<.0001	0.4276	0.3418	0.2061	0.1095	0.2308	0.0571	**<. 0001**	0.395	**<. 0001**
PxH	**<.0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**
PxM	0.5851	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HxM	0.7512	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PxHxM	0.9982	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Simple effect analysis did not indicate significant main effect.

Table 2. Probability of High Risk Group Membership as a function of box MASS, starting HEIGHT, and hand PLACEMENT

		PLACEMENT			
MASS	HEIGHT	Position A	Position B	Position C	Position D
5kg	90cm	22.3	20.3	24.5	24.0
	60cm	28.4	26.5	28.8	28.3
	30cm	28.5	28.0	30.3	29.9
10kg	90cm	31.9	27.5	32.6	32.5
	60cm	36.0	34.6	36.7	36.3
	30cm	36.6	36.6	38.1	38.0

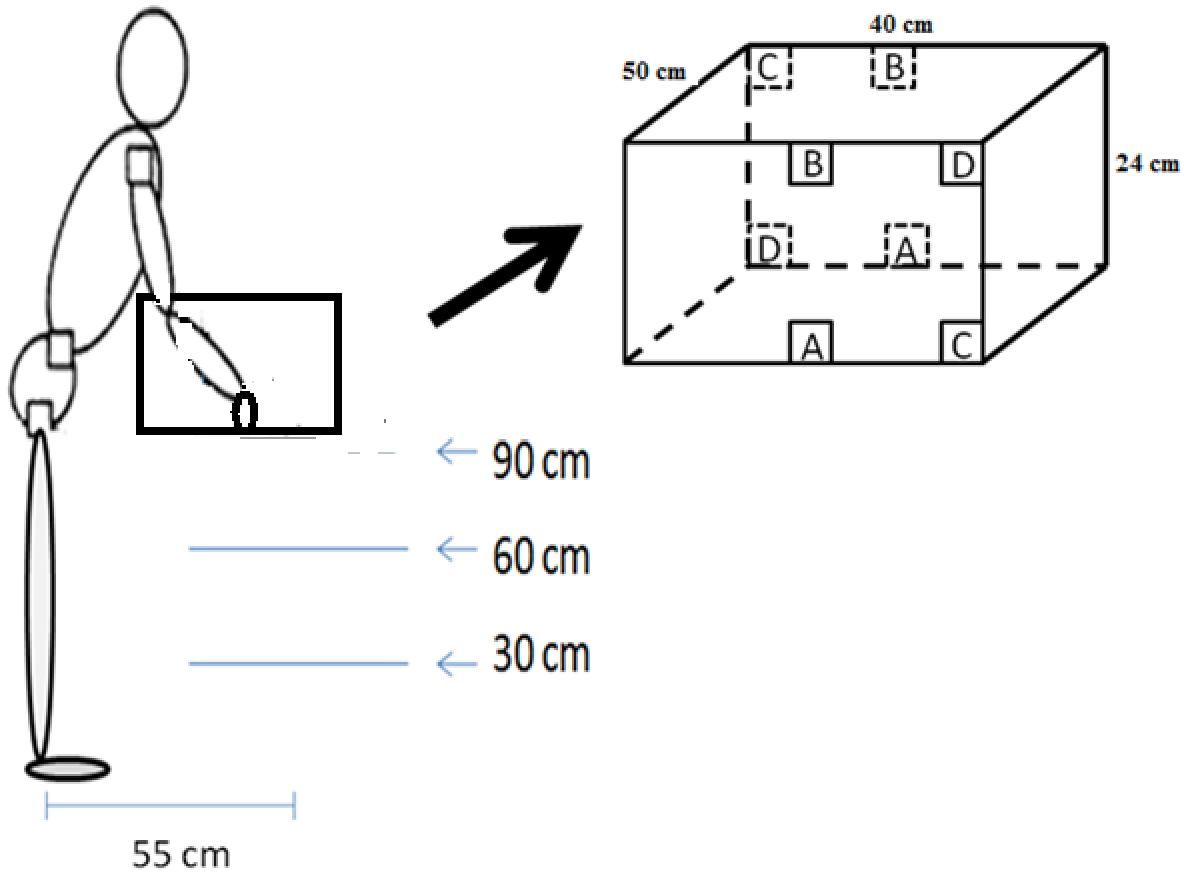

Figure. 1. Illustration of the vertical and horizontal position of the box and hand locations A, B, C, and D. The participant on the left is depicted with hands in the A position.

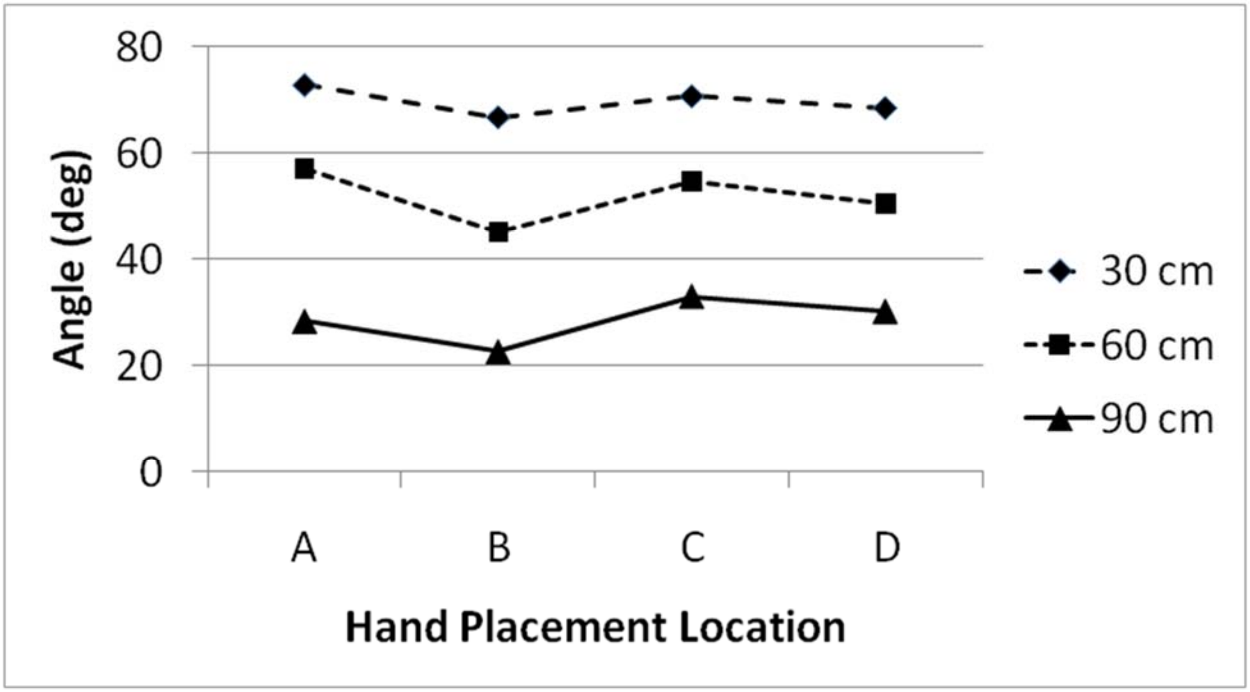

Figure 2. Interaction between PLACEMENT and HEIGHT on peak sagittal angle.

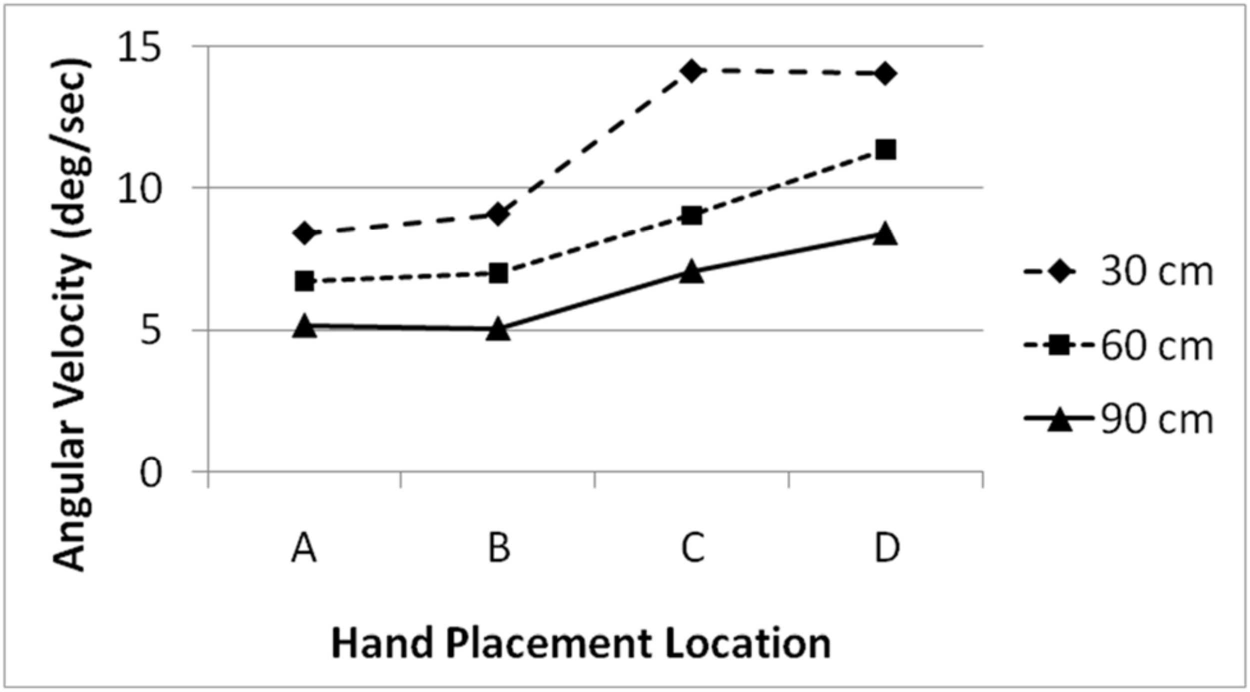

Figure 3. Interaction between PLACEMENT and HEIGHT on peak coronal velocity.

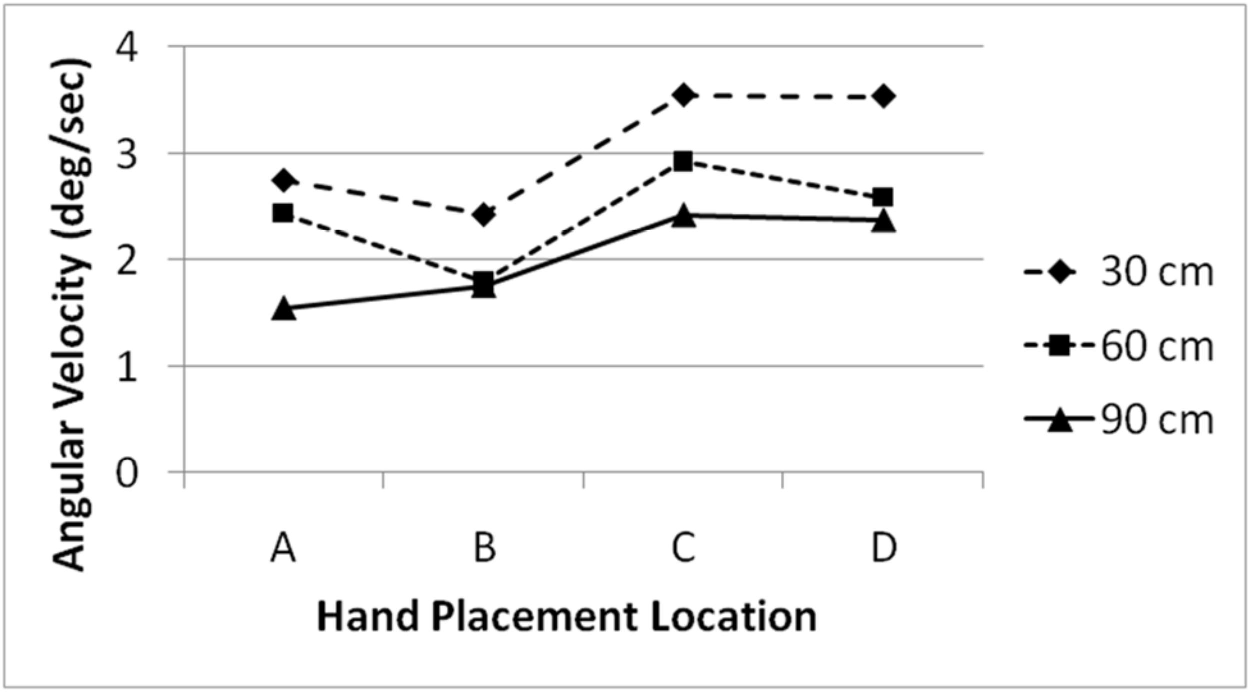

Figure 4. Interaction between PLACEMENT and HEIGHT on mean transverse velocity.

Figure 5. Interaction between PLACEMENT and HEIGHT on PHRGM.