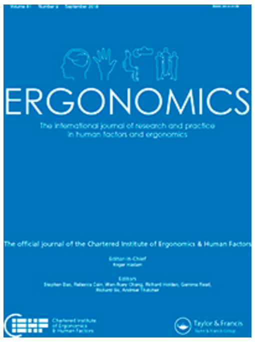

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Handle positions and angles in a dynamic lifting task
Part 1. Biomechanical considerations

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This first part of a two-part paper describes the biomechanical (body and box angle) measurements taken during a study of manual lifting and lowering of cubic boxes. Fifteen male and fifteen female manual materials-handling workers lifted and lowered boxes with all combinations of two handle angles to the horizontal (35° and 70°) and four handle positions (three asymmetric and one symmetric) through three lifting (lowering) distances (floor–waist, waist–shoulder, floor–shoulder; reversed for lowering). Angles were measured at each of five stages of lift or lower between floor and shoulder heights. The main accommodation of the subject to the changing demands of the task was to let the handle 'slip' with respect to the hand so that the handle was mainly gripped with either the first or fourth digits. This 'slippage angle' could be minimized with a 70° angle between handle and box horizontal and by choosing an asymmetric handle position with one hand in the centre of the lower edge and the other in the centre of the front edge of the box. A box design incorporating hand-hold cut-outs with these features is proposed.

1. Introduction

A series of studies aimed at recommending optimum handles for boxes has been reported over the last several years. Early work (reviewed in Drury 1980) concentrated on size, shape and texture of handles, reaching the conclusion that handles should be about 110 mm long, about 25–40 mm in diameter, cylindrical in shape and with a smooth, non-slip surface. An industrial survey (Drury *et al.* 1982) showed that the most frequently used hand positions on boxes without handles were asymmetric, with symmetrical positions only being used with heavy, compact boxes. Using the handle position convention shown in figure 1, positions 3/7 (asymmetrical) and 8/8 (symmetrical) were those used most frequently.

A laboratory experiment using a static box-holding task at waist height, reported by Coury and Drury (1982), showed that the asymmetric positions (3/8, 6/8) gave the lowest physiological and perceived strain while the symmetrical position (8/8) gave the lowest hand-forces on the handles. A more general experiment (Deeb *et al.* 1985) used a static box-holding task at floor, waist and shoulder heights. Again, the asymmetrical positions (3/8 and 6/8) were found to be good at all holding heights with symmetrical positions (2/2 and 8/8) being recommended where the box weight was great enough (13 kg) for minimizing the hand forces to be a first priority.

The best angle of handle to box horizontal axis was found by allowing the handles to pivot. The pivoted angle, corrected for the residual wrist deviation and slippage between hand and handle, was found to be around 50° at floor level and 80°–120° at greater task heights. Overall, an angle of 70° was recommended as a reasonable compromise.

Other results of note were that subject population (student or manual materials-handling worker) and subject gender had little effect on the recommendations. In

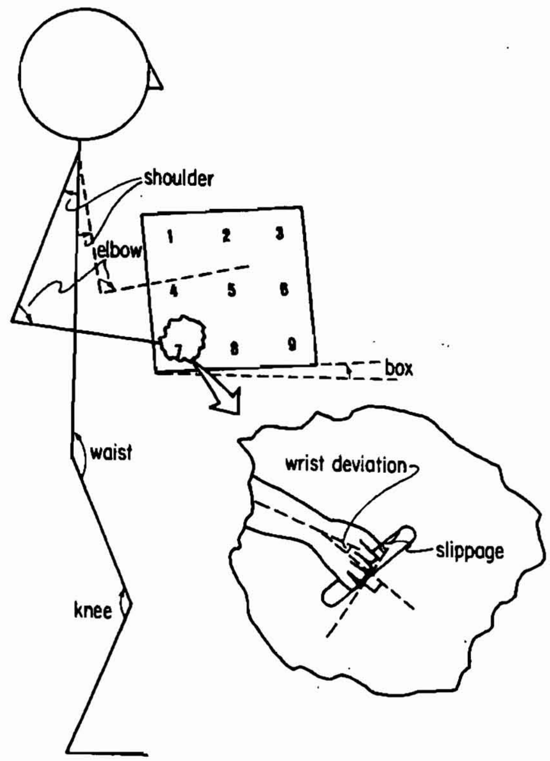


Figure 1. Definitions of handle positions and angles measured.

addition, the recommended positions and angles did not change with box size and box weight. Thus any recommendations can be expected to have wide generality.

However, the experiments noted above were all performed with a static task and a pivoting handle which locked in position when the load was lifted. It is important to know whether the recommendations derived from such a task would be sustained under dynamic conditions and with fixed handles. Hence the experiment reported here used a lifting task over three distances (floor to waist, waist to shoulder, floor to shoulder) and used boxes with hand-hold cut-outs in the four best handle positions so far tested (2/2, 3/7, 3/8, 6/8). Handle angles were fixed at either 70° to the horizontal (the optimum from the static experiments) or 35° (midway between 70° and the usual 0°).

Because of the large number of independent variables, this paper reports on the biomechanical measures only. Physiological and psychophysical measures were also taken and these are reported in Part 2, which also makes final handle recommendations for handling of box-like containers.

2. Methodology

2.1. *Subjects*

Thirty manual materials handlers, fifteen males and fifteen females, were recruited from local industry. Their age, height, weight and experience statistics are given in table 1. The anthropometric data is representative of the general population. For comparison, 1985 projected mean U.S. body size data (NASA 1978) are as follows:

Males:	Stature 1·784 m	Weight 81·5 kg
Females:	Stature 1·628 m	Weight 59·7 kg

Table 1. Summary statistics on subjects.

	Males ($n=15$)		Female ($n=15$)	
Statistic	Mean	±SD	Mean	±SD
Height (m)	1·753	0·071	1·615	0·064
Weight (kg)	80·5	11·7	65·3	19·0
Age (years)	24·6	4·9	24·9	8·4
Experience (months)	32·0	25·1	52·0	59·6

Comparing these with table 1 shows that the subjects in this experiment were very close to population norms, with the exception of the females who were somewhat heavier (almost 6 kg) than the norms. As with other manual materials-handling tasks, young, relatively inexperienced people predominate.

2.2. *Materials*

Two plywood containers measuring 400 mm × 400 mm × 400 mm (16 in × 16 in × 16 in) were constructed. Hand-hold cut-outs were made in each lateral face at positions 2, 3, 6, 7 and 8, following the convention of figure 1. Hand-hold cut-outs, in the 11 mm (0·43 in) thick plywood, were oval in shape with semi-circular ends of 19 mm (0·75 in) radius joined by straight sides of length 100 mm (3·94 in). The angle between the straight portions and the horizontal axis of the container was 70° on one container and 35° on the other. Each container weighed 11 kg (24·2 lb) where the load distribution was such that its centre of gravity was in the centre of the box. The following handle position pairs were used: 2/2, 3/7, 3/8 and 6/8.

Side-view photographs were taken with a Bolex H-16 movie camera, fitted with a 10 mm lens, loaded with Tri-X black-and-white reversal 16 mm film and running at 18 frames per second. A large front-surfaced mirror was placed on the left side of the subject so that accurate measurements, using a mathematical transformation with respect to a standardized reference plane, could be made of the posture of each side of the body on a single film.

A Beckman Dynograph was used to record the subject's heart rate throughout the experiment.

2.3. *Procedure*

Each subject was medically examined, given a description of the experiment to read and a consent form to sign providing he/she agreed to participate. Electrodes were attached for heart rate measurement. Each subject then performed eight lifts and eight lowers in each of the 24 conditions which were presented in a different random order to each subject. The 24 conditions were a factorial combination of three distances of lift/lower (floor–waist (F–W)/waist–floor (W–F), waist–shoulder (W–S)/shoulder–waist (S–W), floor–shoulder (F–S)/shoulder–floor (S–F)), two handle angles (70°, 35°) and four handle positions (2/2, 3/7, 3/8, 6/8). For each condition, one lift and lower was performed every 15 seconds to give a two-minute work period. Recovery between conditions was at least two minutes but was always until the heart rate had returned to its initial resting level.

2.4. *Measurements*

The biomechanical measures (dependent variables) are defined below and illustrated in figure 1.

(*a*) Box Angle (BA): the angle between the bottom of the box and the horizontal.
(*b*) Wrist Deviation Angle (WA): the angle between the lower arm (ulna) and the third metacarpal.
(*c*) Slippage Angle (SA): the angle between the handle axis and a line at 90° to the third metacarpal. (This represents the degree to which the subject fails to grip the handle with the whole width of the hand.)
(*d*) Elbow Angle (EA): the angle between midlines of lower arm and upper arm.

These biomechanical indices were measured digitally from the movie film at the following stages (see figure 2).

Stage 1. Floor level (box on floor).
Stage 2. Midway between floor and waist.
Stage 3. Waist level (centre of box at waist).
Stage 4. Midway between waist and shoulder.
Stage 5. Shoulder level (centre of box at shoulder).

To insure accuracy of digitization at the working plane, a calibration series of limb segments at different angles was drawn onto a large wooden board. These angles were filmed and digitized (for both left and right-side views) and measured angles calibrated against known calibration angles. The calibration equations were used to calculate the true angle from each measured angle.

Only lifts 5 and 7 of the series of 8 lifts were digitized.

All measures were subject to an ANOVA in which the factors were gender (G), distance of lift (D), angle of handle (A), hand position (P), trials (T) (lift 5 vs lift 7), and stage of lift (S), at the five levels defined above. The BMDP statistical package was used for all analyses.

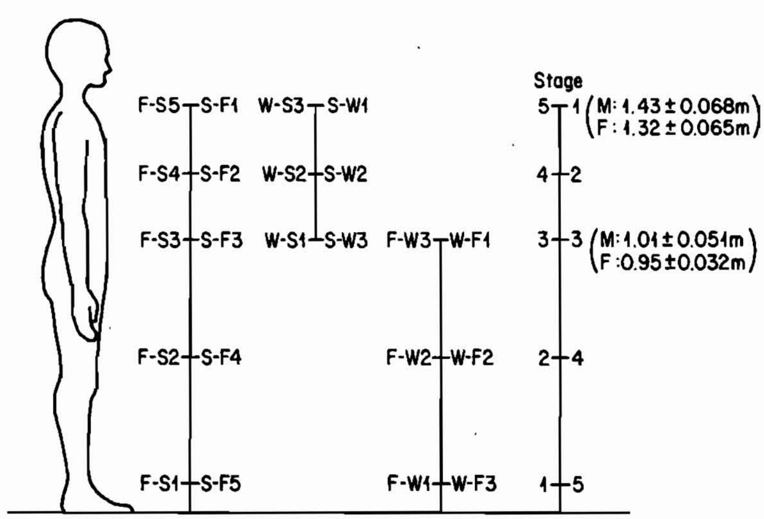


Figure 2. Stages of lifting and lowering at three lift/lower distances. For all figures: F–W, floor to waist; W–F, waist to floor; W–S, waist to shoulder; S–W, shoulder to waist; F–S, floor to shoulder; S–F, shoulder to floor. Bars show standard error(s) for the means plotted.

3. Results

3.1. *Effects of lifting/lowering distance*

Each stage of lift occurred in at least two distances of lift. For example, Stage 1 occurred in both floor–waist and floor–shoulder lifts and in both waist–floor and shoulder–floor lowers (see figure 2). Before the main analysis could be performed (i.e., an analysis across stages), the question of whether the distance of lift (i.e., its origin and destination) affected the body angles at a particular stage needed to be examined. For example, whether the elbow angle at Stage 1 was dependent upon whether the lift would end at the waist (F–W) or shoulder (F–S) and similarly for lowering. An ANOVA was conducted for each angle and each stage to determine whether the distance of lift (D) was significant and whether it produced any significant interactions. The results of these analyses of variance are summarized in table 2 (for lifting) and table 3 (for lowering) for the main effects and first-order interactions only.

Figures 3, 4, 5 and 6 show the size of these effects for box, elbow, wrist and slippage angles respectively. While lifting and lowering were different, as will be noted later, the main interest here is in the difference between distance of lift/lower at each stage. For box angle, the differences were numerically small (up to 3°) and consistent in that the box was tilted back more at the lower end of a short box movement and tilted forward more at the upper end. Both elbows were somewhat more extended (maximum 14°) for short movements at all stages up to Stage 4 but were almost equal at Stage 5. Wrists were more ulnar deviated for short movements, particularly from waist level upwards (maximum difference 11°). Slippage angles were smaller for short movements below the waist (up to 12°) and larger for short movements in the upper stages (up to 5°). It was deemed that these effects were small and consistent enough to perform deeper analysis mainly on the full distance of lifting and lowering.

3.2. *Main analysis of lifting and lowering*

For each lift/lower distance, an ANOVA was performed on each measured angle. These were five factor ANOVA's with gender, stage, handle angle, handle position, and trial as factors. The results for lifting and lowering, in terms of patterns of effects, were very similar with highly significant main effects of stage, handle angle and handle position, and a highly significant stage × handle position interaction for almost all measures. Very few other interactions were seen except for an occasional handle angle × handle position interaction for elbow angles. Because of this similarity, a six-factor factorial ANOVA was performed on each measure at each lift/lower distance, with the sixth factor being movement direction (M), at two levels, lifting and lowering. Table 4 shows this ANOVA.

The major main effects were movement direction (M), stage of lift/lower (S), handle angle (A), and handle position (P). Gender was never significant and rarely involved in interactions, confirming earlier results. Trial number (T) was only just significant ($P<0{\cdot}05$) for three of the analyses and was only involved in seven of the 105 possible first-order interactions. The major first-order interactions were movement direction × stage, movement direction × handle position and stage × handle position. The movement direction × stage interactions have already been shown in figures 3 to 6. These figures show that lowering produced numerically larger angles than lifting for each angle measured. For box, elbow and wrist angles, interactions were in the sense of less difference between lifting and lowering at the extreme stages (1 and 5) and more difference around waist level. The slippage angle results showed a numerically small interaction effect and merely emphasized how small the absolute sizes of interactions

Table 2. Summary of ANOVAs between lift distances at each stage.

Stage	Comparison	Variable (Angle)	G	D	A	P	T	G×D	G×A	D×A	G×P	D×P	A×P	A×T
1	F–W1/F–S1	Box		**	***	**							***	
		R. Elbow		***	**	***				*		*	**	
		L. Elbow		**	***	***				*			***	
		R. Wrist		*	***									
		L. Wrist			***	**								
		R. Slippage		***	***	***								
		L. Slippage		***	***	***								
2	F–W2/F–S2	Box		***	*	***						***		*
		R. Elbow		***	***	***						*	*	
		L. Elbow		***	***	***							***	
		R. Wrist		***	***	***								
		L. Wrist		***	***	***	*							
		R. Slippage		***	***	***								
		L. Slippage		***	***	***				*				

3	F–W3/W–S1/F–S3	Box	***	*	***		***				***	*
		R. Elbow	***	**	***					*	***	***
		L. Elbow	***	***	***			**		*	***	***
		R. Wrist	***	***	***				*		***	
		L. Wrist	***	***	***				*		*	
		R. Slippage	***	***	***						***	
		L. Slippage	***	***	***						**	
4	W–S2/F–S4	Box	*		***							
		R. Elbow		***	***							*
		L. Elbow		***	***			*		*	**	*
		R. Wrist	***	***	***				*			
		L. Wrist	***	***	***	*						
		R. Slippage	***	***	***							
		L. Slippage	***	***	***							
5	W–S3/F–S5	Box	***	**	***							
		R. Elbow		*	***							
		L. Elbow		***	***			*		***	***	
		R. Wrist	**	***	***	*						
		L. Wrist	**	***	***	*					*	
		R. Slippage	***	***	***							
		L. Slippage	***	***	***						**	

*, $p < 0{\cdot}05$; **, $p < 0{\cdot}01$; ***, $p < 0{\cdot}001$. Factors in ANOVA are G, gender; D, distance of lift; A, angle of handle; P, position of hand; T, trial number. Lifts are as follows: F–W, floor to waist; W–S, waist to shoulder; F–S, floor to shoulder.

Table 3. Summary of ANOVAs between lower distances at each stage.

Stage	Comparison	Variable (Angle)	G	D	A	P	T	G×D	G×A	D×A	G×P	D×P	A×P	D×T	P×T
1	S–F1/S–W1	Box		***	*	***						*			
		R. Elbow			*	***									
		L. Elbow			**	***					***	**	*		
		R. Wrist		*	***	***									
		L. Wrist		**	***	***		*				*			*
		R. Slippage		***	***	***						*			
		L. Slippage		***	***	***	*				*	***	*		
2	S–F2/S–W2	Box			*	***						*			*
		R. Elbow		***	**	**						***	**		
		L. Elbow			***	***						*	***		
		R. Wrist		***	***	***		*		**		***	**		
		L. Wrist		***	***	***		*				**	*		
		R. Slippage		**	***	***									
		L. Slippage		***	***	***	*				**	**	**		

3	S–F3/S–W3/W–F1	Box	***	*	***				*					
		R. Elbow	***	***	***						***	***		
		L. Elbow	***	***	***		*	*		*	**	**		
		R. Wrist	***	***	***		*		*		***	**		*
		L. Wrist	***	***	***		**				*			
		R. Slippage	***	***	***	*					***			
		L. Slippage	***	***	***					**	***		**	
4	S–F4/W–F2	Box	***	*	***								*	
		R. Elbow	***	***	***						**			
		L. Elbow	***	***	***			*			*	***		
		R. Wrist		***	***	*							*	
		L. Wrist		***	***					*				*
		R. Slippage	***	***	***	*								
		L. Slippage	***	***	***						***	**		
5	S–F5/W–F3	Box	***		***							*		
		R. Elbow	*	**	***							***		
		L. Elbow		***	***							***		
		R. Wrist	***	***	***	**								
		L. Wrist	***	***	***	*						**		
		R. Slippage	***	***	***	**								
		L. Slippage	***	***	***	*					***	**		

*, $P<0.05$; **, $P<0.01$; ***, $P<0.001$. Factors in ANOVA are G, gender; D, distance of lower; A, angle of handle; P, position of hand; T, trial number. Lowers are as follows: S–W, shoulder to waist; W–F, waist to floor; S–F, shoulder to floor.

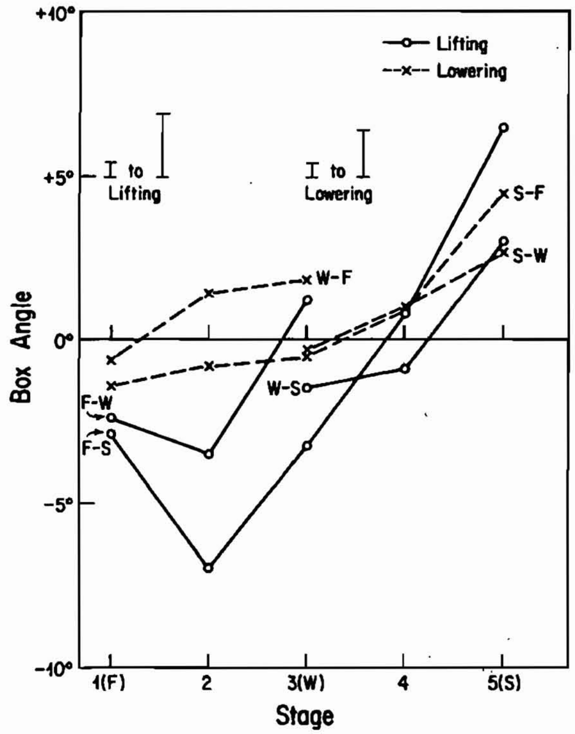
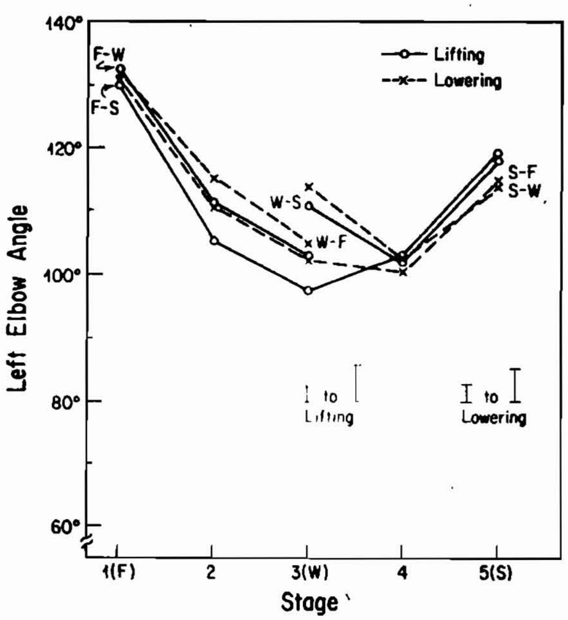
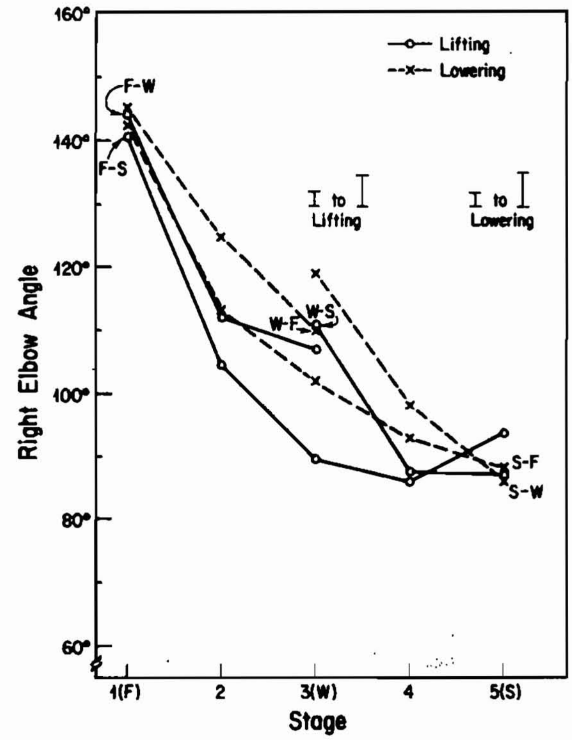


Figure 3. Lift/lower and distance difference for box angle.

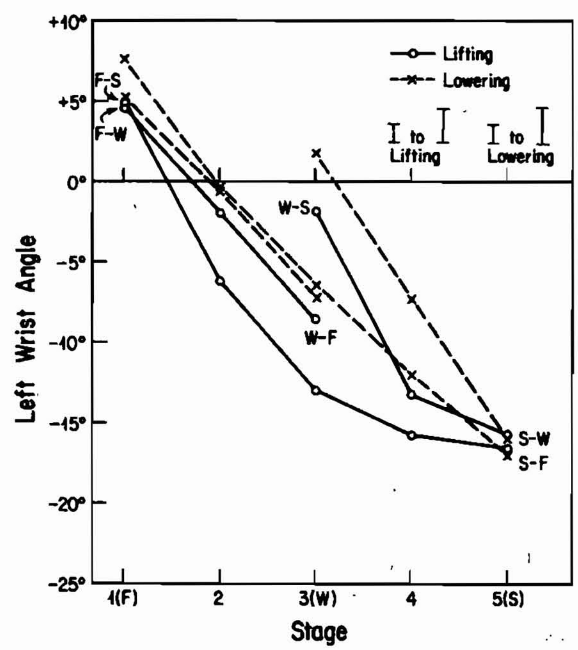


(*a*)



(*b*)

Figure 4. Lift/lower and distance differences for elbow angle.



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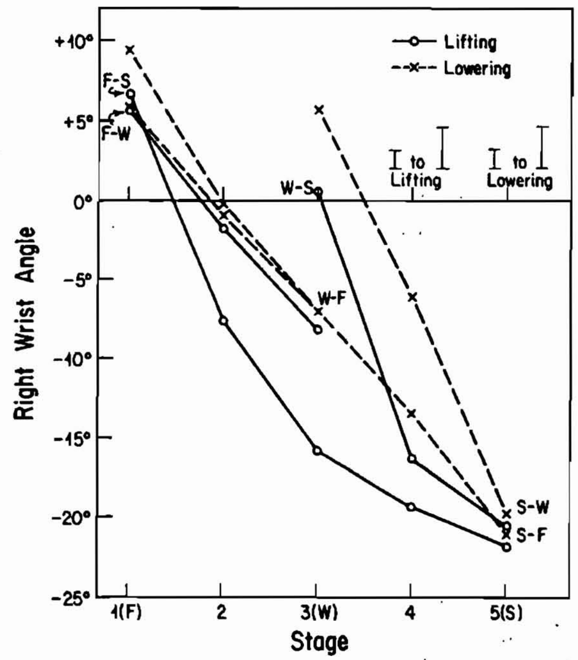
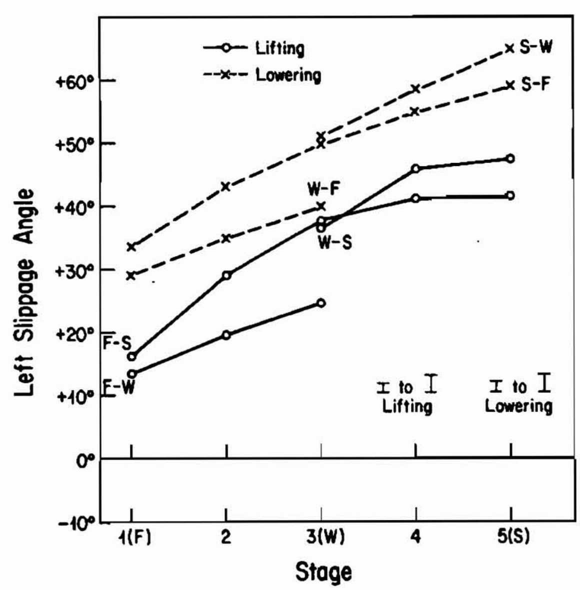
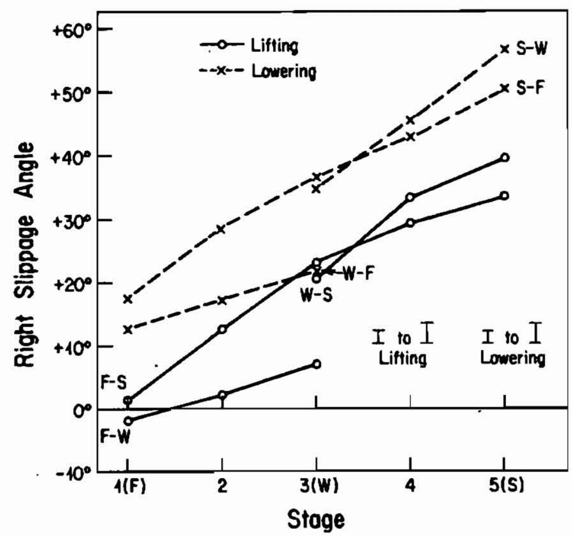


(*b*)

Figure 5. Lift/lower and distance differences for wrist angle.



(*a*)



(*b*)

Figure 6. Lift/lower and distance differences for slipping angle.

can be despite statistical significance in a large experiment. In a similar manner, examination of the M × P interaction showed little of practical interest.

As noted earlier, the lift distances did not differ too greatly from each other and hence remaining results will be presented for the full lift/lower distances only. The handle angle effects for lifting and lowering are shown in table 5. There is considerable consistency between lifting and lowering for all angles except the slippage angles. The (significant) differences between the 35° and 70° handle angles for all measures except slippage, never exceed 6°. Slippage angle, however, produces interesting results. For the lifting task, there is much less slippage at 70° than at 35°, with the difference being almost the same magnitude as the difference in the handle angles on the boxes. At a 35° handle angle, the subjects had about 35° of slippage in lifting. In lowering, however, slippage angles were much closer between the two handle angles (3° to 4°). For both hands in lowering, the slippage angles at the 35° handle angle were within 3° of their values in lifting. For the 70° angle, however, slippage angles did not fall to the low values they had done in lifting. In more physical terms, subjects accommodated to the poor handle angle of 35° by not gripping the handle with the whole hand in lifting, while in lowering, neither handle angle was gripped with the whole hand. The effect in lowering was one of 'hanging' the box from the first fingers and letting it pivot as it fell.

The major interaction found was stage × handle position (S × P) for lifting and lowering, hence this is plotted for all measures as it also shows the main effects of stage and handle position. Figures 7–10 show the S × P interaction for lifting and lowering. In lifting, as the box was raised from floor level, it first tilted forward and then (at Stage 4) changed to a backward tilt (figure 7). At the same time, the elbow started extended at floor level, flexed to waist level and, for the upper hand (both hands in position 2/2), re-extended towards shoulder level. For the lower hand (right), the elbow remained flexed as the shoulder level was reached (figure 8). Wrist angle showed a smooth change from slight radial deviation at floor level to 15°–20° of ulnar deviation at shoulder level (figure 9).

Table 4. Summary of ANOVAs between stages for lifting versus lowering at each height.

Lift/lower height	Stages	Variable (Angle)	G	M	S	A	P	T	G×M	G×S	M×S	G×A	M×A	S×A	G×P	M×P	S×P	A×P	M×T	S×T	A×T
F–W/W–F	1–3	Box		***	***	**	*		*	*	***					***	*				
		R. Elbow		***	***	**	***				***						**	***			
		L. Elbow		*	***	***	***				**						***	*			
		R. Wrist		*	***	***	*									***	**				*
		L. Wrist		***	***	***	***									***	***				
		R. Slippage		***	***	***	***						***								
		L. Slippage		***	***	***	***	*					***			*	***		*		
W–S/S–W	3–5	Box		***	***		***		*		***			*		***	***			**	
		R. Elbow		***	***	*	***	*			***				*	***	***	***			*
		L. Elbow			***	***	***				***				***	***	***				*
		R. Wrist		***	***	***	***				***			***			***	**			
		L. Wrist		***	***	***	***			*	***			***		**	***	*			
		R. Slippage		***	***	***	***				***		***			**	***				
		L. Slippage		***	***	***	***				***		***			***	***	*			
F–S/S–F	1–5	Box		***	***						***					***	**				
		R. Elbow		***	***	***	***				***					***	***				
		L. Elbow			***	***	***	*			***	**		*		***	***	***			
		R. Wrist		***	***	***	***				***			*			***		**		
		L. Wrist		***	***	***					***					***	***				
		R. Slippage		***	***	***	***				***		***			**	***			*	
		L. Slippage		***	***	***	***				***	*	***			***	***	**			

*, $P<0{\cdot}05$; **, $P<0{\cdot}01$; ***, $P<0{\cdot}001$. Factors in ANOVA are G, gender; M, movement of direction; S, stage of lift/lower; A, angle of handle; P, position of hand; T, trial number.

Table 5. Effects of handle angle (35° versus 70°) on mean values of each measure.

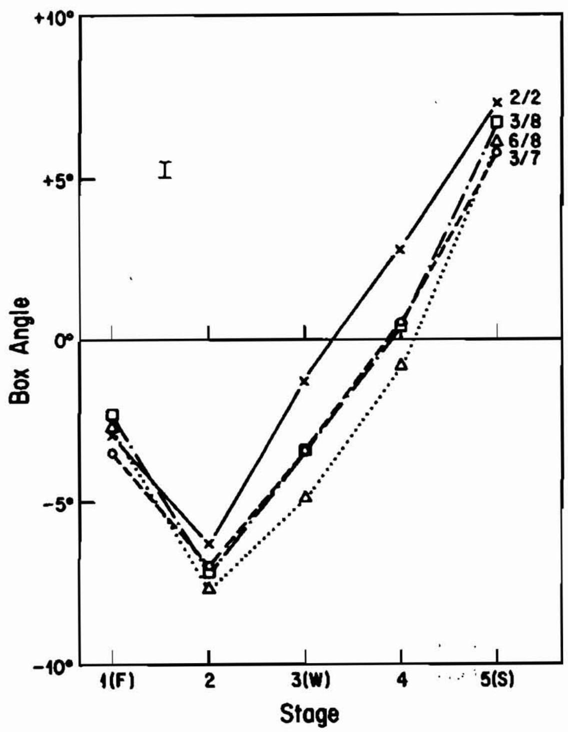
		Lifting		Lowering	
Measure		HA35°	HA70°	HA35°	HA70°
Box angle		(not significant)			
Elbow angle (degrees)	Right	104	100	110	107
	Left	108	114	109	115
Wrist angle (degrees)	Right	−13	−10	−8	−5
	Left	−11	−8	−8	−4
Slippage angle (degrees)	Right	35	5	32	39
	Left	50	16	47	50

As the box was lowered from the shoulder, it first tilted backward and then (at Stage 3, waist level) changed to a forward tilt (figure 7). At the same time, for the upper hand (left), the elbow was moderately extended at shoulder level, flexed at waist level and re-extended at floor level. For the lower hand (right), the elbow started flexed at shoulder level, moderately extended at waist level and almost fully extended at floor level (figure 8). Wrist angle showed a smooth change from ulnar deviation (15°–20°) at shoulder level to 5°–10° of radial deviation at floor level (figure 9).

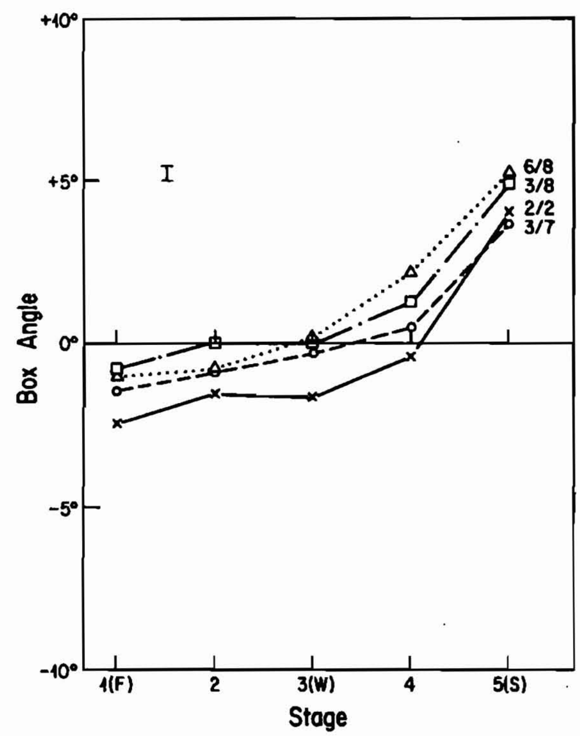
Handle position effects, while highly significant for most of the three measures presented so far, were not large in some instances. For box angle, about 2° of tilt covers the whole range, with position 2/2 being consistently lower (more forward tilt) than the asymmetric positions during lowering. Angles of the right elbow (figure 8) show different patterns for 6/8 and 3/8, 3/7 and 2/2. The first two are closely similar, as the right hand is in the same position for each. Position 2/2 shows a more flexed elbow than the first two, except at shoulder height. Position 3/7, which involves a reach by the right hand to the lower front corner of the box, shows that the right elbow is progressively flexed in a monotonic manner throughout the height range. Angles of the left elbow show a close correspondence with those of the right elbow only for position 2/2, as expected with bilateral symmetry. Position 3/7 is now much closer to positions 3/8 and 6/8 throughout the range. Wrist angles for the two sides and two movement directions show close correspondence between handle positions, with a tendency for position 3/7 to be more neutral (closer to a straight wrist) throughout. This tendency never exceeds 5°.

The slippage angle results (figure 10) need more care in interpretation. All the results in figures 7 to 10 are averages across both handle angles (35° and 70°). For slippage angle, the handle angle effect was quite large in lifting so that a neutral slippage angle on figure 10 (lifting) would be +16° for the 70° handle angle and −16° for the 35° handle angle. The neutral position for the 70° handle angle is the main one of interest and is marked on both lifting parts of figure 10. The upper (left) arm gave neutral slippage near the floor level and gradually increased, with position 6/8 remaining most neutral except at the floor level where 3/8 was the most neutral. For the lower (right) arm, neutral position was reached at about waist level, with positions 3/8 and 6/8 being closest to neutral throughout. As the handle positions were closely grouped for wrist angle, the implication is that position 6/8, and to a lesser extent 3/8, minimized the accommodation of the body to the box for the better of the two handle angles (70°).

For the lowering task, a totally different image appears. The handle angle effect was much smaller than in lifting for slippage angle; a neutral slippage angle (figure 10)

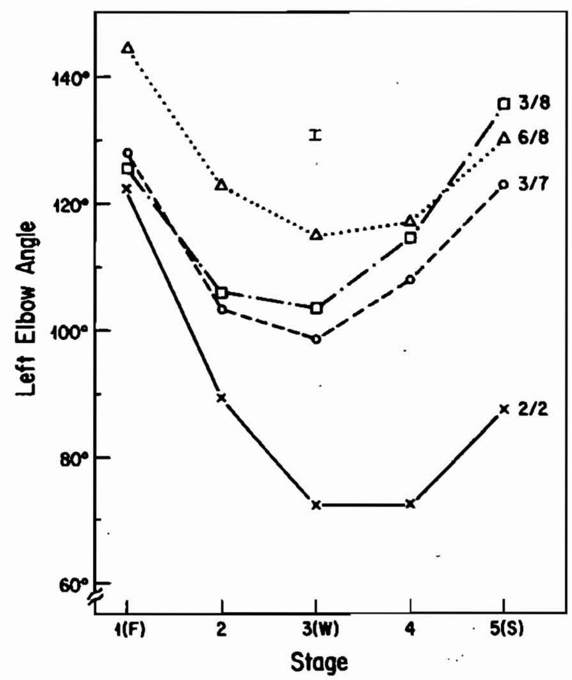


(*a*)

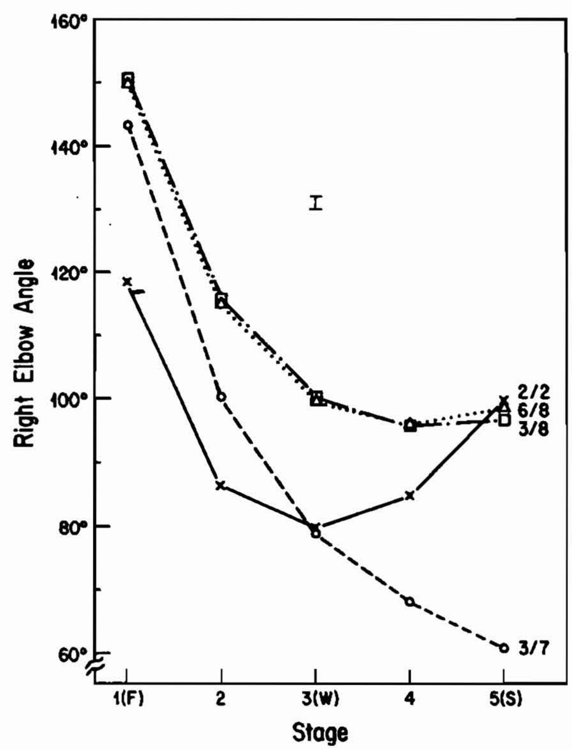


(*b*)

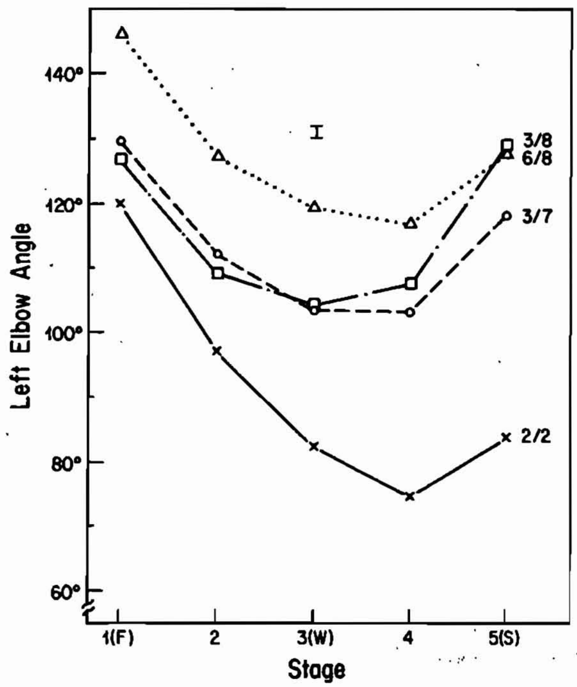
Figure 7. Stage × handle position interaction for box angle. (Lifting (*a*), lowering (*b*).)


Left Elbow Angle
140°
120°
100°
80°
60°
3/8
6/8
3/7
2/2
1(F)
2
3(W)
4
5(S)
Stage

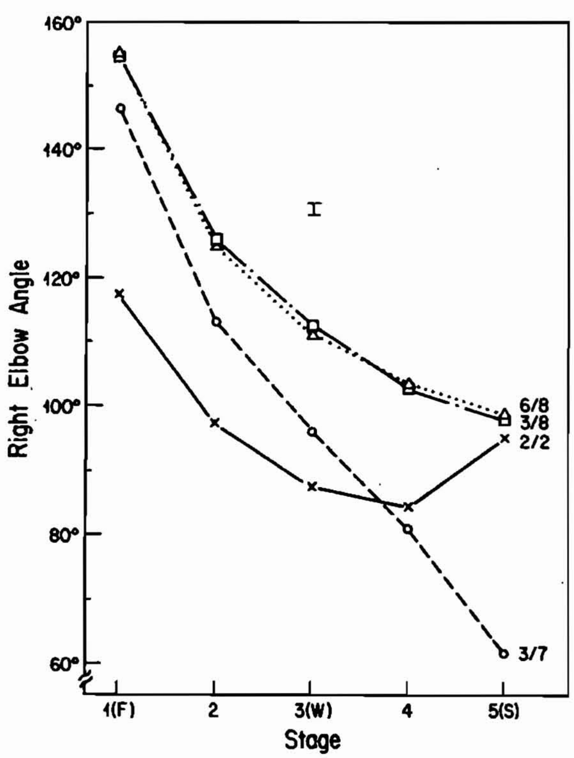
(*a*)


Right Elbow Angle
160°
140°
120°
100°
80°
60°
2/2
6/8
3/8
3/7
1(F)
2
3(W)
4
5(S)
Stage

(*b*)

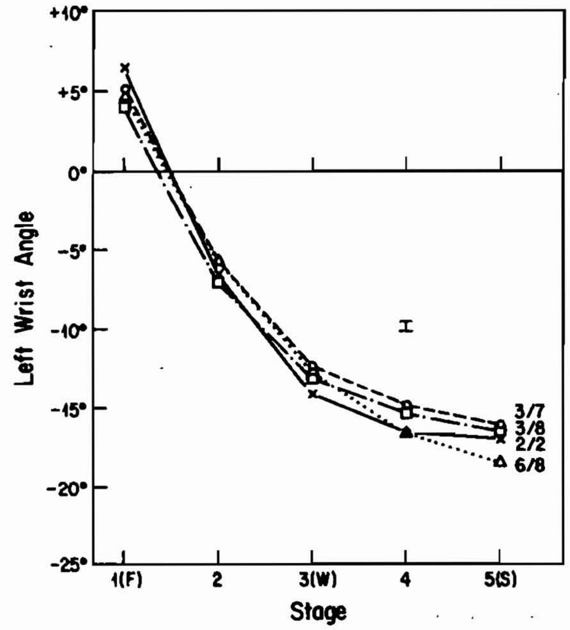


(*c*)

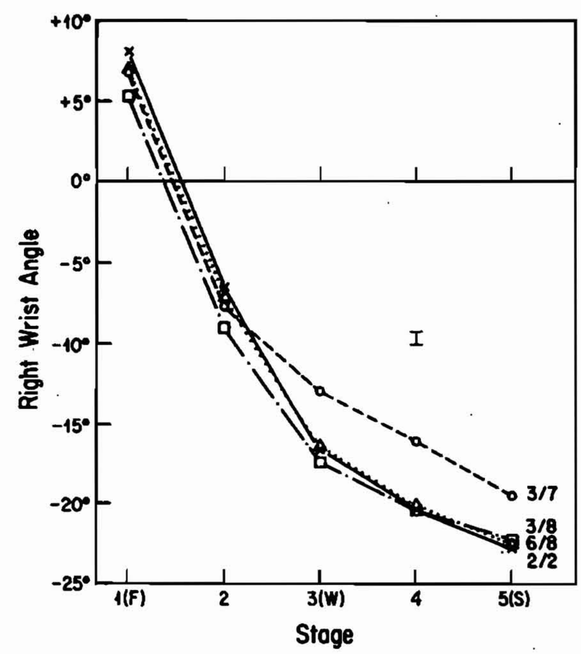


(*d*)

Figure 8. Stage × handle position interaction for elbow angle. ((*a*), (*b*), lifting; (*c*), (*d*), lowering.)


+10°
+5°
0°
-5°
-10°
-15°
-20°
-25°
Left Wrist Angle
1(F)
2
3(W)
4
5(S)
Stage
3/7
3/8
2/2
6/8

(*a*)


+10°
+5°
0°
-5°
-10°
-15°
-20°
-25°
Right Wrist Angle
1(F)
2
3(W)
4
5(S)
Stage
3/7
3/8
6/8
2/2

(*b*)

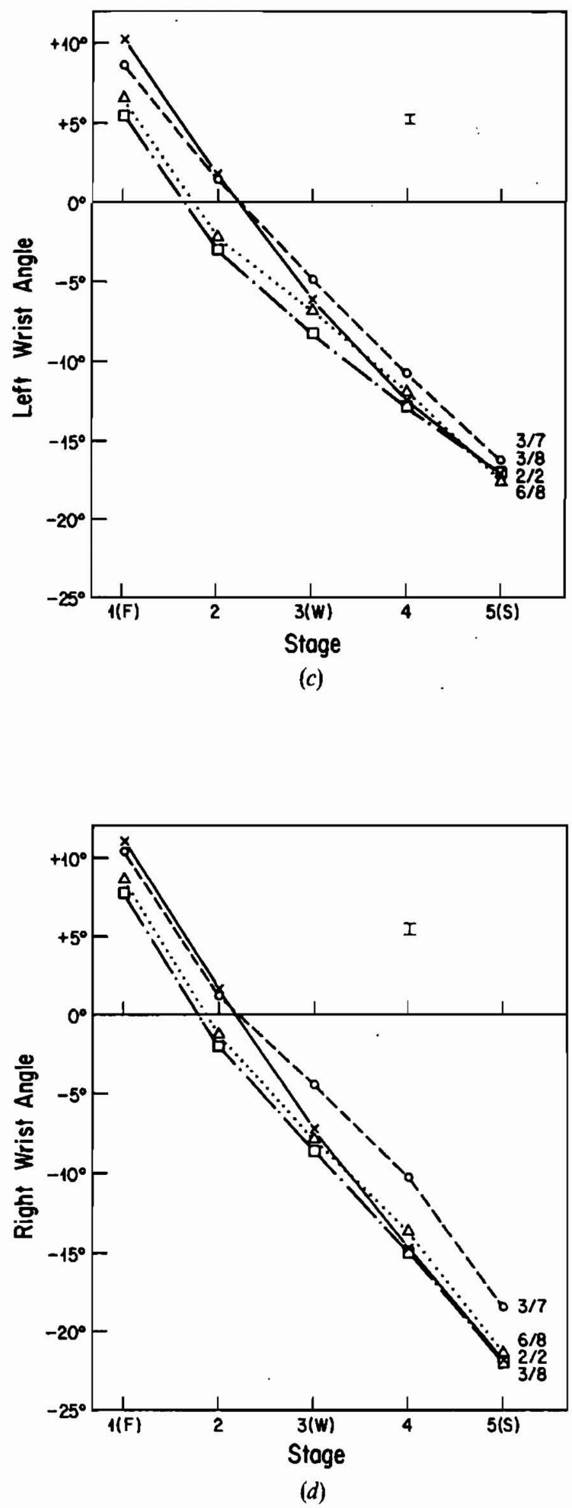
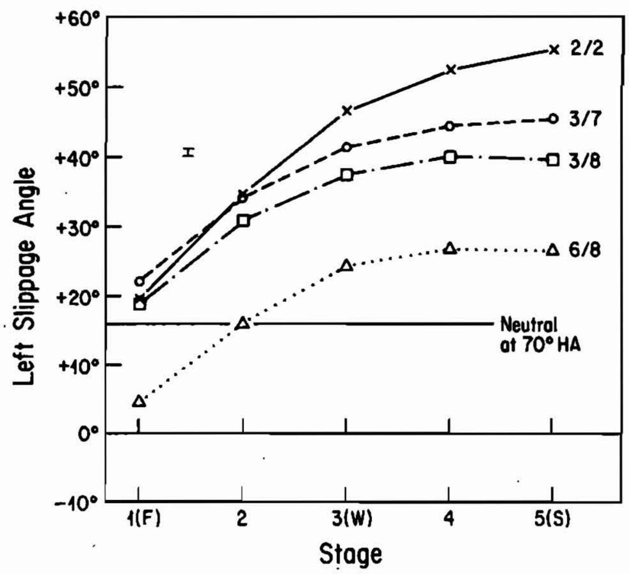
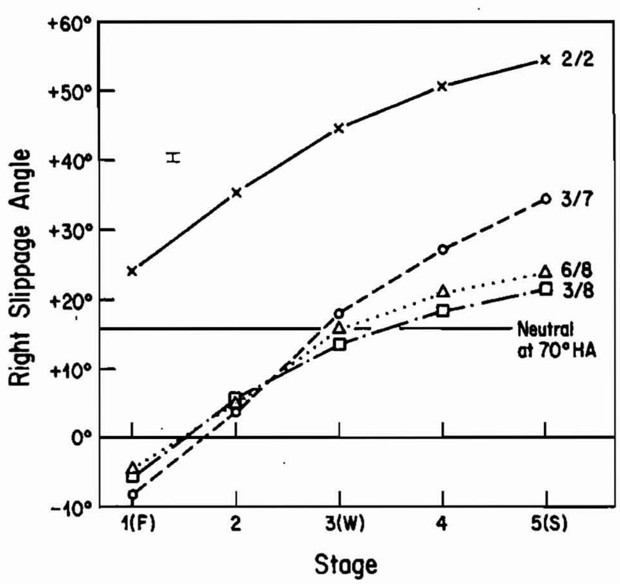


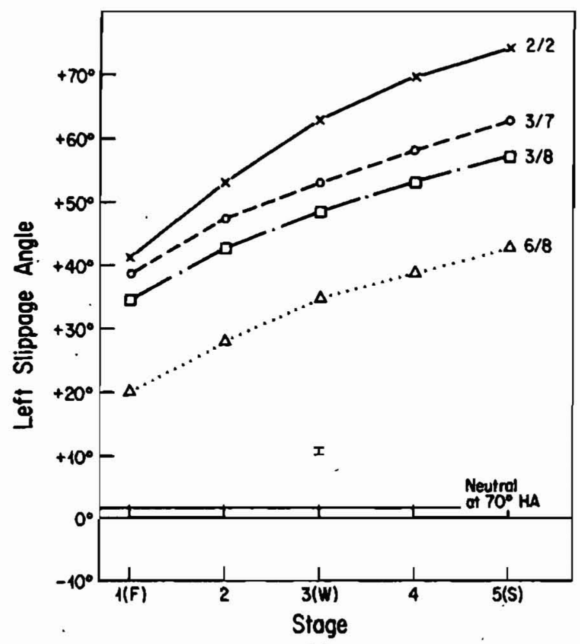
Figure 9. Stage × handle position interaction for wrist angle. ((*a*), (*b*), lifting; (*c*), (*d*), lowering.)


+60°
+50°
+40°
+30°
+20°
+10°
0°
-10°
Left Slippage Angle
2/2
3/7
3/8
6/8
Neutral
at 70° HA
1(F)
2
3(W)
4
5(S)
Stage

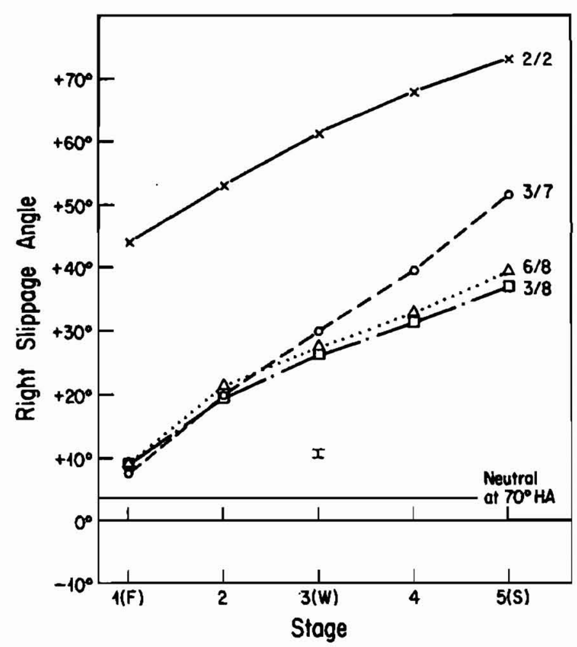
(a)


+60°
+50°
+40°
+30°
+20°
+10°
0°
-10°
Right Slippage Angle
2/2
3/7
6/8
3/8
Neutral
at 70° HA
1(F)
2
3(W)
4
5(S)
Stage

(b)



(c)



(d)

Figure 10. Stage × handle position interaction for slippage angle. ((a), (b), lifting; (c), (d), lowering.)

would be +2° for the 70° handle angle for the upper arm (left) and +4° for the 70° handle angle for the lower arm (right). The upper (left) arm shows that it was never neutral at any of the levels, even though hand position 6/8 was the closest to neutral of the four positions. The lower (right) arm was closest to neutral near the floor level but all three asymmetric positions were very closely grouped. The symmetrical position (2/2) gave the greatest slippage for both hands.

One noticeable finding was that where the same hand positions occurred more than once (2/2 on both hands, 3/7 and 3/8 on the left hand, 3/8 and 6/8 on the right hand), the results were closely comparable in all of figures 7 to 10. This finding enables handle angle recommendations to be made with some confidence.

4. Discussion

With such a large data set (about 30 000 data points), effects small in absolute magnitude reach high levels of statistical significance. Hence this discussion will concentrate on the practical questions posed in the Introduction. Do the findings of this dynamic task support the earlier, static, results? What recommendations on handle positions and angles can be made on the basis of biomechanical findings?

The biomechanical measures showed few gender or trial effects. This finding, when combined with earlier findings of no box-weight or box-size effects on body and box angles, gives confidence that recommendations will be applicable quite generally to the lifting population and the boxes they lift.

The consistency that was expected between lifting and lowering and between origin and destination never occurred. The body angles at a particular stage were different depending on where the origin was and what the destination was. Therefore, different destinations, lowering or lifting, gave different expectations and a change in behaviour of the subjects. The consistency between lifting and lowering has a significant effect on any recommendation or design.

The lowering task showed that subjects did not use the handles as expected. They increased their slippage angles, which in turn increased their wrist angles (table 6). Subjects were carrying the box, while lowering it, so that the box was simply hung on their fingers without holding the handle with the full breadth of their hand. The change in task was so large that it changed the criteria for design. Merely taking the average of lifting and lowering for any common design would not serve any purpose as it would be far away from either of the two values. Since lifting showed a 'better' use of the handle with much smaller wrist and slippage angles, even though subjects still failed to hold the handle with the full breadth of the hand, this suggests using the lifting task as the major criterion for design.

The biomechanical variables (upper limb and box angles) clearly showed handle position and handle angle effects. Their generalizability is somewhat marred by the findings (table 4) that different angles may apply at the start and end of lifts/lowers to those found at the same stage of a continuous lift. However, this finding does not affect handle position recommendations. Positions 6/8 and, to a lesser extent, 3/8 were seen in both lifting and lowering to have the lowest slippage angles of the four positions tested. The only exception was that a symmetrical position, 2/2, may be better for handling boxes at floor level. These findings confirm those of the static experiments.

Slippage between hand and handle was the major mechanism by which the body accommodated to an imperfect handle angle, with wrist deviation as a lesser accommodation. Again this was the finding of one-handed static tests (Drury *et al.* 1985). Slippage angle was minimized for the 70° handle angle and, indeed, the 35°

handle angle produced about an extra 35° of compensating slippage. It is possible to add together slippage angle, wrist deviation angle and box angle to find the angle which the handle should have had to fit the body with no slippage, deviation or box tilting. When two measurements were available at the same handle position (e.g., 2/2 right and 2/2 left, or 3/8 left and 3/7 left), a close correspondence was found between these sums with no difference exceeding 6° except for left elbow angle in lifting (10°). In this way, the following angles were obtained to give zero wrist and slippage angles in lifting.

Handle position	2	3	6	7	8
Optimum angle (degrees)	83	76	60	56	50

Note that the criterion of slippage angle being identically zero may not be entirely appropriate. As the grip spans of digits 4 and 5 are smaller than those of digits 2 and 3, there will always be a tendency for the hand to assume a small but positive slippage angle if all digits are to be equally in contact with the handle or cut-out. Against this anatomical argument, however, is the fact that the grip force contribution from digits 2 and 3 is (and should be) greater than that from digits 4 and 5 because of strength differences between the digits. Hence a slippage angle criterion of zero is not an unreasonable assumption.

The handle angles quoted above are remarkably close to the 70° specified as a result of the static tests. If these recommendations are combined with the handle position recommendation of 6/8, then a box with suitable hand-hold cut-outs in its sides would look as shown in figure 11. This has cut-outs which can be used from either side, with angles of 60° for position 6 and 50° for position 8. Both the recommended asymmetric position (6/8) and the most frequent symmetric position (8/8) can be used, the latter for floor-level movements of heavy boxes. If necessary, a 'Position 3' could be added in each top corner of the box with, say, a 75° angle, giving 3/8 as an alternate position. However, no straight handle will minimize wrist deviation and slippage angle at all task heights.

Would such a box be practical? The cut-outs do not seriously weaken the container and can easily be incorporated into containers which use moulded packaging material

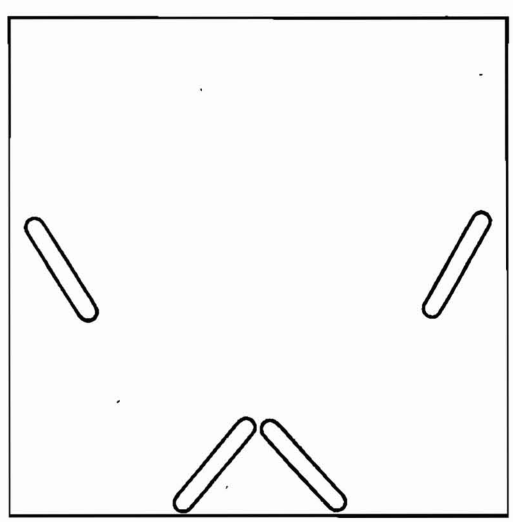


Figure 11. Proposed handle positions on a container.

between product and container. In containers which are tightly packed (e.g., groceries), the cut-outs could be arranged to lie between items of product for cylindrical items. For tightly-packed products in rectangular packages, a false wall would be needed approximately 25 mm inside the outer container wall to provide finger clearance. For containers used inside a factory and reused, moulded-in handles as shown would be simple to design.

What would be the advantages of such a box? Handles reduce dropping (Rigby 1973) and reduce the probability of a box slipping which can lead to a loss-of-balance or strain-during-recovery accident. Handles reduce the cost (physiological and subjective) of the task to the worker and hence can be expected to reduce recovery times. In box handling jobs, they would be expected to reduce trapping, pinching or cutting of the hands and fingers which Powell *et al.* (1971) showed to be a major source of injuries in a shipping area.

5. Conclusions

(1) The dynamic lifting experiment largely confirmed the results of earlier static tests.
(2) Optimum box handle positions are 6/8 (or 3/8) for most lifts, with 2/2 useful for heavy boxes at floor level.
(3) The handle in position 6 should be at 60° to the box horizontal, while that in position 8 should have an angle of 50°.
(4) These findings are likely to be valid across a wide range of workers, box sizes and box weights.

Acknowledgment

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Cet article comporte deux parties: dans la première, on décrit les mensurations biomécaniques (corps et angles d'une boîte) relevées au cours d'une étude de levage et de dépose de boîtes cubiques. Quinze hommes et quinze femmes manutentionnaires devaient soulever et déposer des boîtes comportant toutes les combinaisons d'angles des poignées par rapport à l'horizontale (35° et 70°) et quatre positions des poignées (trois asymétriques et une symétrique) avec trois hauteurs de levage (et dépose): sol-ceinture, ceinture-épaule, sol-épaule (inversé pour la dépose). Les angles ont été mesurés pour chacune des cinq phases de levage et dépose entre le sol et la hauteur de l'épaule. La principale adaptation des sujets aux astreintes variables de la tâche était de laisser 'glisser' la poignée dans la main de manière à ce qu'elle soit fermement agrippée avec le premier ou quatrième doigt. Cet angle de 'glissement' peut être réduit en introduisant un angle de 70° entre la poignée et l'horizontale de la boîte et en choissisant une position asymétrique de la poignée; c'est-à-dire une main au milieu du bord inférieur et l'autre au milieu du bord avant de la boîte. On propose un modèle de boîte comportant une telle disposition des poignées.

Der erste Teil einer zweiteiligen Studie beschreibt biomechanische Messungen (Kōrper und Raumwinkel der Kiste), die während einer Untersuchung über das manuelle Anheben und Absenken von quadratischen Kisten durchgeführt wurden. Fünfzehn männliche und fünfzehn weibliche Arbeiter, die manuell Materialien handhaben, hoben und senkten Kisten ab, wobei zwei verschidene Winkel (35° und 70°) zwischen dem Griff und der Horizontalen und vier Griffpositionen (drei asymmetrische und eine symmetrische) bei drei Anhebungs- bzw. Absenkungsstrecken (Boden-Taille, Taille-Schulter, Boden-Schulter; umgekehrte Reihenfolge für das Absenken) kombiniert wurden. Die Winkel wurden in jeder der fünf Stufen des Anhebens oder Absenkens zwischen dem Boden und der Schulterhöhe gemessen. Die Hauptabstimmung mit der Versuchperson hinsichtlich der wechselnden Anforderungen der Aufgabe war, den Griff unter Rücksichtnahme auf die Hand 'rutschen' zu lassen und zwar so, daß der Griff hauptsächlich entweder mit dem ersten oder dem vierten Finger erfaßt wurde. Dieser 'Schlupfwinkel' könnte durch einen Winkel von 70° zwischen dem Griff und der Kiste in der Horizontalen und durch die Wahl einer asymmetrischen Griffanordnung minimiert werden, wobei sich eine Hand in der Mitte der tieferen Kante und die andere in der Mitte der vorderen Kante befindet. Eine Gestaltung der Kiste mit herausgeschnittenen Griffen nach diesen Merkmalen wird vorgeschlagen.

本論文は全２部から成る論文の第１報目にあたり，立方体の箱を上げ下げする時の生体力学的測定（からだと箱の角度）について述べたものである。男女15名ずつの荷役作業者に対し，水平面に対する取っ手角度を２種類（35°及び70°），取っ手の位置を４種類（非対称３種類と対称１種類）に変化させ，３種類の持ち上げ距離（床面-腰の高さ，腰の高さ-肩の高さ，床面から肩の高さ）について，すべての条件の組み合わせで箱の上げ下ろしを行わせた。床面と肩の高さの間での上げ下ろしの５つの段階で角度の測定を行った。作業条件の変化に対して被験者が行う主な調整は，主に第１指と第４指で取っ手を握る様に手に対し取っ手を「ずらす」ことであった。この「ずらし角度」は取っ手と水平面との角度が70°で，一方の取っ手が箱の下端の中央に，もう一方が前面の端の中央に位置する様な非対称な配置を選択した時最小となった。これらの形状にさらに手づかみ用切り込みを加えた箱のデザインを提案する。

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