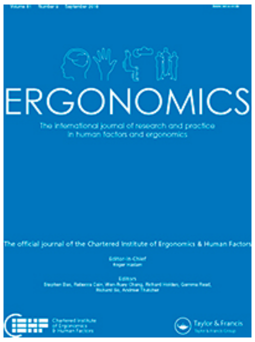

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Evaluation of a curved handle and handle positions for manual materials handling

By J. M. DEEB, C. G. DRURY and B. MCDONNELL

State University of New York at Buffalo,
342 Bell Hall, Amherst, New York, 14260, U.S.A.

Previous studies of handles for two-handed box handling have shown that the best angle for a handle on a box varies with height above the floor. In order to minimize the accommodation between handle and wrist required at different heights, a curved handle was proposed. Six manual materials handling workers lifted 9 kg and 13 kg boxes between conveyors at floor and waist heights for three minutes while body angles were analysed from video tape recordings. Two symmetric and two asymmetric handle positions were tested. Both straight and curved handles resulted in excellent hand/handle fit but were not significantly different from each other on any measures.

1. Introduction

With the high and non-decreasing magnitude of the problem of industrial manual materials-handling injuries, Snook's (1978) point that redesigning the container and the task is more effective than redesigning the operator is well taken. Improving the operator/container coupling by providing handles was an approach identified in NIOSH's research goals (Herrin *et al.* 1974) and confirmed by many authors since. Handles can increase the maximum force exerted on the container and reduce task energy expenditure (Garg and Saxena 1980, Mital and Ayoub 1981).

Previous studies have explored the design and utility of box handles (Coury and Drury 1980, Drury *et al* 1982, Deeb *et al.* 1985, Drury and Deeb 1986). Starting with an industrial survey of box handling and a laboratory study of static box holding, handle positions and angles have been evaluated for physiological, psychophysical and biomechanical stress. Using the definitions of handle positions and limb angles in figure 1, various conclusions have been reached:

(1) Handle positions which are symmetrical (e.g., 2/2 and 8/8) produce the lowest forces at the handles and are associated in industry with heavy, compact boxes handled at floor level.
(2) Handle positions which are asymmetric (e.g., 3/8, 6/8, 3/7) minimize perceived cost and heart rate and provide the horizontal and vertical stability required in handling large but lighter containers.
(3) The hand accommodates to the handle angle both by deviating the wrist and by allowing slippage between hand and handle.

The need for both accommodations can be minimized by providing a handle perpendicular to the forearm, but the angle required will vary with the height at which the box is lifted or held. At floor height handles should be nearer to horizontal, while at waist and shoulder heights the handles should be more nearly vertical. The following compromise handle angles were recommended on the basis of the studies so far: handle position 2 (handle angle 85°), 3 (76°), 6 (60°) and 8 (50°).

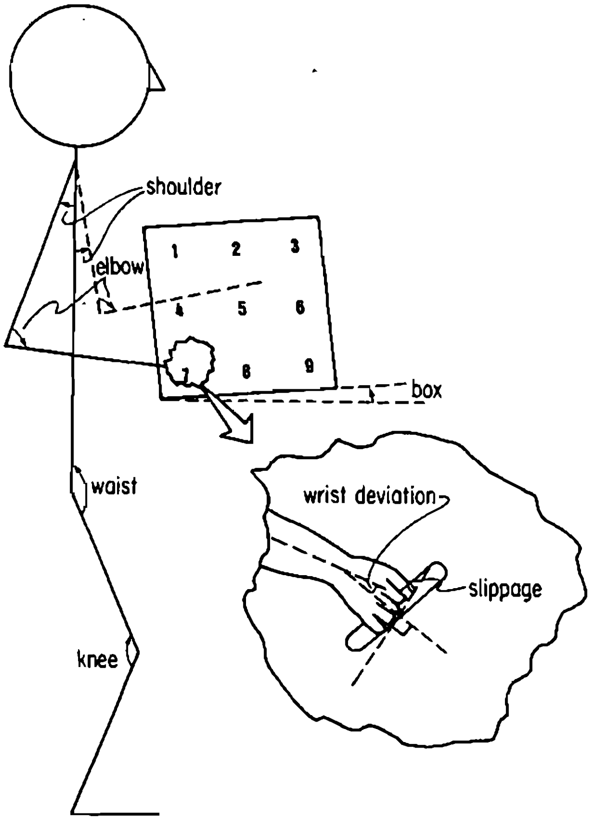


Figure 1. Definitions of handle positions and angles measured.

The experiment reported here was an attempt to go further in optimizing handle angle by introducing handles which could effectively take on many different angles. Straight handles (actually hand-hold cut-outs in cardboard boxes) at the angles given above were replaced by curved cut-out handles. The curve of each handle was chosen to cover the handle angles which would be best at each task height. At the top of each handle, the curve was close to horizontal while at the bottom it was nearer to the vertical. Hence a subject could slide the hand along the curve to minimize slippage and wrist deviation. A possible disadvantage with such handles would be their propensity to allow the box to slip if the grip were not maintained. However, this would only produce a change of effective handle angle, not a dropping of the box, as the hand would rest at the end of the cut-out after slipping.

In addition, the experiment was designed to test the optimum handle angles (above) over a longer and more realistic task period. Subjects performed 30 lifts over three minutes rather than the eight lifts over one minute of the previous experiment. This longer duration allowed heart rate to further approach equilibrium at work, while a six-minute rest period allowed fuller recovery.

The hypotheses were that

(1) Curved handles should require less accommodation by the subject than straight handles.

(2) Straight handles at the optimum angles should require little accommodation even without curving.

As in previous research (Drury and Deeb 1986), the effects of lack of fit between handle and human were measured indirectly using physiological and psychophysical measures, as well as directly using biomechanical variables. In this experiment, it was possible to measure back angle so that a single biomechanical model could be used to estimate the compressive force on the L5/S1 disc, although no hypotheses were formulated for this measure.

However, before the main experiment using curved handles for a two-handed box lifting task, it was necessary to determine whether handle curvature itself would affect handle/hand fit adversely. Accordingly, a one-handed static holding task, similar to that reported by Drury *et al.* (1985), was carried out with various degrees of handle curvature. Because materials-handling workers were not required for this static task, student subjects were used. The curved handles, and a straight one for comparison, were attached to the top of a briefcase-sized box which was held by the subject in the preferred hand, with heart rate and psychophysical measures being taken on each trial. This study will be described as Experiment 1 and the main study as Experiment 2.

2. Experiment 1. One-handed holding task

The objective of Experiment 1 was to determine whether handle curvature affected physiological and psychophysical cost in a static holding task.

2.1. *Methodology*

2.1.1. *Subjects*

Five male and five female subjects, all students at SUNY at Buffalo, took part. Mean height was 1·80 m (males), 1·63 m (females) and mean weights were 713 N (males), 566 N (females). Subjects were not specifically chosen to be representative of the industrial MMH population.

2.1.2. *Materials*

Two boxes, of weight 88 and 128 N, were used. They were 425 mm long × 215 mm wide × 395 mm high and had a detachable handle mounted 130 mm above their upper surface. This handle was in fact a hand-hold cut-out in either 3 mm ($\frac{1}{8}''$) or 13 mm ($\frac{1}{2}''$) thick wood. Cut-outs were concave upwards with a radius of curvature of 50, 76, 102, 203 mm or straight. Each cut-out was 25 mm wide and 100 mm long with 25 mm diameter rounded ends.

2.1.3. *Procedure*

Each subject performed one trial in each of 20 conditions, comprised of all combinations of two box weights, two handle thicknesses and five handle curvatures. A trial consisted of a 25-second holding period followed by a 95-second resting period. Subjects held the box at one side of their body using a hook grip with their preferred hand. Measures were taken of heart rate over the holding period and of both rated perceived exertion (Borg 1962) and body part discomfort (Corlett and Bishop 1976) at the end of each holding period. Frequency and severity measures of body part discomfort were calculated using the definitions given in Experiment 2.

2.1.4. *Experimental design*

A five-factor repeated measures design was used with subjects (S) nested under gender (G). The other three factors were box weight (W), handle thickness (T) and handle shape (S). All analysis was performed using the BMDP package, with all factors considered as fixed effects, except subjects.

2.1.5. *Results and discussion*

The ANOVA defined above was run on all four measures. No effects of handle shape (S) were found, although the experiment was sensitive enough to detect weight and thickness effects. The two significant interactions, out of 17 calculated (G × T × S, $P < 0{\cdot}05$; G × W × T × S, $P < 0{\cdot}01$), showed no discernible pattern. No gender effects were found, as was the case in the previous static holding task (Drury *et al.* 1985).

For box weight, the three psychophysical scales all showed significance at $P < 0{\cdot}01$. Their mean values are given in table 1.

As expected, there was a large increase in perceived workload with increased box weight.

Use of a thin handle material (3 mm) increased the BPD Severity rating, mainly of the hands and arms, to 2·5 from the value of 2·0 found with the 13 mm material ($P < 0{\cdot}01$). Clearly, distributing the box weight over a smaller area is more painful, as expected.

The main result of Experiment 1 was that no effects of handle radius of curvature were found. Hence it was possible to go ahead with the main experiment and study the biomechanical effectiveness of curved handles of mild curvature (102 mm) as handle curvature itself was not detrimental to handle/hand fit.

Table 1. Mean values and standard errors of the weight in Experiment 1.

Measure	88 N Mean	128 N Mean	Standard error
Rated perceived exertion	11·7	14·6	0·26
BPD frequency	2·7	3·2	0·08
BPD severity	1·9	2·4	0·09

3. Experiment 2. Two-handed lifting task

3.1. *Methodology*

3.1.1. *Subjects*

The object of this first study of curved handles was to determine whether the idea was worth pursuing further. Six male subjects were recruited from the material movement section at the State University of New York at Buffalo. Age, height, weight and experience statistics are given in table 2. The subjects were very close to the projected 1985 mean U.S. body size data (NASA 1978) in height but were somewhat heavier (almost 8 kg) than these projected means. Each subject was examined by a medical doctor and, if pronounced fit to participate, was given a typed description of the experiment to read and an informed consent form to sign prior to the experiment.

Table 2. Subject characteristics, six subjects.

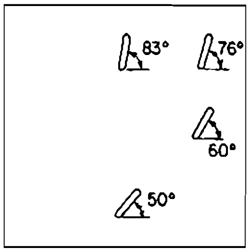
Statistic	Min	Mean	s.d.	Max	Population norms†
Age, years	25	31·3	17·91	56	
Height (m)	1·67	1·79	0·090	1·91	1·78
Weight (kg)	72	89·5	20·14	125	81·5
Job experience (months)	24	100	80·9	156	—

† Population norms taken from NASA (1978) projected mean U.S. body size data.

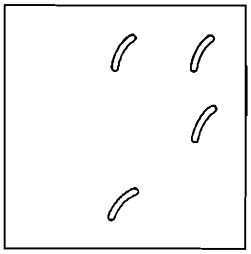
3.1.2. *Materials*

Boxes measuring 400 mm × 400 mm × 400 mm were constructed from cardboard. Hand-hold cut-outs, straight or curved, were made in each lateral face at positions 2, 3, 6 and 8 (figures 2 (*a*) and (*b*)) following the convention of figure 1. The curved handles had a 150 mm radius of curvature and were positioned at the same angle to the vertical as the equivalent straight handle, measured at the mid-point of the handle. Two weights, 88 and 128 N, were tested, representing easy and moderately difficult loads as in earlier experiments. The load distribution was such that its centre of gravity was in the centre of the box. The following handle position pairs were tested: 2/2, 3/8, 6/8 and 8/8.

Two sections of a gravity roller conveyor system, each 3·05 m long, were set up at two different levels, the lower section on floor level and the upper section at 0·76 m above floor level. Both conveyors were set up at a slope so that boxes came to the



Straight Handles
(*a*)



Curved Handles
(*b*)

Figure 2. (*a*) Straight handles with their respective angles to the box. (*b*) Curved handles.

subject at floor level, were lifted by the subject up to 0·76 m and rolled away automatically. Side-view photographs were taken with two video cameras located one at each side. A Beckman dynograph (Model R611) was used to record the subject's heart rate throughout the experiment.

3.1.3. *Procedure*

Three electrodes were attached to the subject for heart rate measurement. Each subject performed ten lifts per minute, for a three-minute work period, in each of the 16 conditions, which were presented in a different random order to each subject. Boxes were presented to each subject in the form of batches where each batch consisted of boxes of a single weight and handle shape. The start of each working period was initiated by the experimenter. Each subject had to pick the box off the lower conveyor and load it onto the upper one. Boxes at the other side of the upper conveyor were picked up and fed to the lower one in such a way that the work performed by the subject was constant and at a steady state with no interruption.

Each three minutes (30 lifts) of work was followed by six minutes of rest to simulate typical industrial cycles such as palletizing of boxes. Subjects were free to use any lifting technique they preferred as all were experienced manual materials handlers. It took subjects about four hours to complete the experiment.

Subjects were given a choice of which hand to use on which handles (e.g., 3/8 could be left hand in number 3 position on the left lateral side of the box and right hand in number 8 position on the right lateral side of the box or with the hands reversed) as only a small effect of hands was found in the study by Coury and Drury (1982). Five out of six subjects had their left hand uppermost. For the one subject (left-handed) who had his right hand uppermost, the data presented here have been transposed left for right so that the upper hand can be referred to as 'left' throughout this paper. All subjects thus used their preferred hand for the lower hand position, where more force was expected to be exerted (Coury and Drury 1982).

3.1.4. *Experimental design*

This experiment was a multi-factor repeated measures design. The 16 conditions were a factorial combination of two handle shapes (curved, straight), two weights (88 N, 128 N) and four handle positions (2/2, 3/8, 6/8, 8/8). Another factor with two levels (floor, waist) was used in the analyses of the biomechanical indices. All the above-mentioned factors were fixed while subjects was a random factor; hence, the design was a mixed model. The rationale for treating subjects as a random factor was that subjects were chosen from the population of interest, manual materials handlers. Hence, despite the small sample size, inferences may be made about the parent population. The BMDP statistical package was used for all analyses.

3.1.5. *Measurements*

Three sets of indices were used:

(1) Physiological index
  (*a*) Heart rate (HR): in beats per minute (b.p.m.) measured every 30 s during the working and resting period. Therefore six readings during work and 12 readings during rest were measured. Previous studies in this series had shown that heart rates at work rose only to modest levels (110–130 b.p.m.) so that rapid stabilization and rapid recovery were expected.

(2) Psychophysical indices
  (*a*) Rated perceived exertion (RPE): Borg's scale (1962) rated after each condition (3 minutes of work).
  (*b*) Body part discomfort frequency (BPDF): Frequency of non-zero ratings on Corlett and Bishop's (1976) scale, rated after each condition (3 minutes of work).
  (*c*) Body part discomfort severity (BPDS): Mean severity of all non-zero ratings on the above scale.

(3) Biomechanical indices (see figure 1).
  (*a*) Box angle: the angle between the bottom of the box and the horizontal.
  (*b*) Elbow angle: the angle between midlines of lower arm (joining the lateral epicondyle and the lunate bone) and upper arm (joining the acromion and the lateral epicondyle).
  (*c*) Wrist angle: the angle between the midline of the lower arm (joining the lateral epicondyle and the lunate bone) and the line joining the midpoint on the wrist and the third metacarpal.
  (*d*) Slippage angle: 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).
  (*e*) Back angle: the angle between the vertical and the line joining the acromion and greater trochanter (hip joint).
  (*f*) Disc compressive force (DCF): calculated at L5/S1 disc for floor and waist levels using the simple static model of Drury *et al.* (1983).

These biomechanical indices were measured digitally, at the floor and waist levels, from the video tapes using a Hewlet-Packard 9825A computer with digitizer. Only the 15th lift was digitized both to allow a number of lifts for warm-up and to minimize end-of-run effects.

3.2. *Results*

The significance levels of all main effects and interactions are shown in table 3 (physiological and psychophysical indices) and table 4 (biomechanical indices). Handle shape was not significant for any of the indices.

3.2.1. *Physiological and psychophysical variables*

Analyses of variance of the physiological and psychophysical variables showed that weight of the box was significant in heart rate and RPE measures ($P<0\cdot05$). Time was significant for heart rate ($P<0\cdot001$) where it was a factor in the analysis. The weight

Table 3. Summary of ANOVA's of physiological and psychophysical indices.

	RPE	Left BPDF	Right BPDF	Left BPDS	Right BPDS	HR working	HR resting
Handle shape (*H*)							
Box weight (*W*)	*					*	
Time (*T*) (HR only)						***	***
W × *T* (HR only)							*

* $P<0\cdot05$, ** $P<0\cdot01$, *** $P<0\cdot001$.

Table 4. Summary of ANOVA's of biomechanical indices.

	Box angle	Left elbow	Right elbow	Left wrist	Right wrist	Left slippage	Right slippage	Disc compressive force	Back angle
Handle shape (H)									
Box weight (W)						*			
Handle position (P)		***	***	***				***	
Level (L)	*	**	*	**	*	*	***	***	
$H \times L$		*			*				
$W \times L$				*					
$H \times W \times P$				*					

* $P<0.05$. ** $P<0.01$. *** $P<0.001$.

× time interaction was significant ($P<0\cdot05$) for recovery heart rate but not in working heart rate. It can be seen from figure 3, which shows both interactions, that the heavier weight (13 kg) had a consistently larger effect on heart rate throughout the working period, but recovery was more rapid for this 13 kg condition. Newman–Keuls range tests ($\alpha=0\cdot05$) were performed on the heart rate means. The results in table 5 show that, for both box weights, after about 1·5 minutes of work and about 2 minutes of rest, heart rate did not change significantly—data useful in the design of subsequent tests of handle design.

Table 6 shows mean RPE and mean heart rate as a function of box weight with the standard error of the means. RPE should be approximately one-tenth of heart rate for a dynamic task such as the one performed here. It can be seen that subjects rated the heavier weight (13 kg) as more physically demanding than the 9 kg weight, as expected. In relation to heart rate, subjects underestimated their exertion with the lighter box, whereas heart rate and RPE for the heavier box corresponded more closely.

Overall body part discomfort frequency and severity did not show any significant effect, probably because of the small sample size used in this experiment compared to earlier experiments using these measures. Body part discomfort scores for each body part are given in table 7. It can be seen that the upper limbs had the highest frequency of discomfort with the order being lower arm (worst), upper arm, hand and shoulder. For the lower limbs, thighs were rated the worst. More detailed ANOVAs were run by

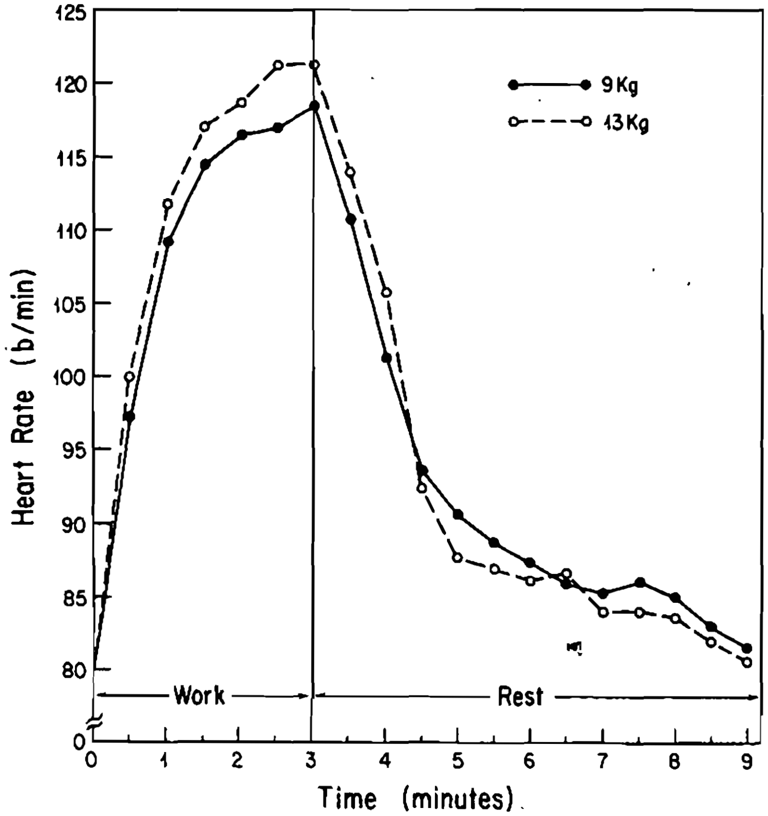


Figure 3. Effect of weight and time ($W\times T$) on heart rate.

Table 5. Newman–Keuls range tests ($\alpha = 0{\cdot}05$).

Heart rate	
88N	128N
Working	
T1<T2 to T6	T1<T8 to T18
T2<T3 to T6	T2<T4 to T6
Resting	
88N	128N
T7≥T8 to T18	T7≥T8 to T18
T8≥T9 to T18	T8≥T9 to T18
T9≥T13 to T18	T9≥T6 to T18

Table 6. Effects of box weight on heart rate and RPE.

	88N	128N	Standard error
Heart rate (b.p.m.)	112	115	0·77
Rated perceived exertion	8·2	10·8	0·43

Table 7. Body part discomfort frequency for each body part. (Percentage trials on which a non-zero reading was obtained.)

Body part	Left		Right
Upper limbs			
Shoulders	9·4		9·4
Upper arms	10·4		10·4
Lower arms	18·8		18·8
Hands	10·4		10·4
Trunk			
Neck		3·1	
Upper back		6·3	
Mid-back		1·0	
Lower back		8·3	
Buttocks		0·0	
Lower limbs			
Thighs	11·4		9·4
Lower legs	6·3		8·3

breaking BPDF and BPDS into body regions following Drury and Deeb (1986), but again no significant effects were found.

3.2.2. *Biomechanical variables*

The analyses of variance of the biomechanical variables (table 4) showed that handle position (P) and Level (L) were significant almost throughout. Table 8 shows these effects as a function of level of lift. For box angle, the differences between levels were numerically small (less than 3°). The box was tilted backwards at the floor level changing to a forward tilt at waist level. Wrist angles showed a radial deviation at floor level. At waist level this changes to a slightly ulnar deviation for the right wrist and a smaller radial deviation for the left wrist. Slippage angle was small and relatively constant with a change of less than 4° between the two levels. Elbow angle showed that at floor level both elbows were moderately extended but at waist level were less extended. Back angle was almost vertical at waist level, with a slight forward flexion at floor level. Reflecting this forward flexion, disc compressive force was quite high at floor level and still moderately high at waist level.

Handle position had a significant effect on both elbow angles, left wrist angle, and disc compressive force (DCF). Table 9 gives the mean values of these variables showing a large difference between the 2/2 position and all others for elbow angle. This difference is mirrored in the DCF values, suggesting that away from the 2/2 position extended elbows increase DCF because of their larger moment arm about the L5/S1 disc.

Table 8. Effects of level of lift on biomechanical variables (angles in degrees).

		Level		Standard error
		Floor	Waist	
Box angle		2	−1	0·8
Wrist angle,	right	6	−1	1·1
	left	11	7	0·9
Slippage angle,	right	−1	2	0·7
	left	2	5	0·7
Elbow angle,	right	132	121	3·0
	left	131	122	1·1
Back angle		55	18	1·1
Disc compressive force (N)		3796	2413	79

Table 9. Effects of handle position on elbow angles and disc compressive force.

	Symmetric		Asymmetric		+Standard error
	2/2	8/8	3/8	6/8	
Elbow angle, right (degrees)	101	136	132	137	2·4
Elbow angle, left (degrees)	102	137	126	140	1·7
Disc compressive force (N)	2820	3097	3273	3252	58

4. Discussion

Heart rate showed the expected rapid increase, levelling out, and rapid recovery of moderate levels of exercise. The levelling out of heart rate in statistical terms took place after about 1·5 minutes of work and 2 minutes of rest in both box weights. Clear differences between the 88 and 128 N box weights were shown throughout the working period. The absolute differences in heart rate between the two box weights were small, less than 5 b.p.m. at any point, but statistically significant, showing that the experiment was indeed sensitive to known effects and that the work/rest cycle was adequate for steady state to have been reached. In manual materials handling, much of the work is done in moving the body rather than the box so that small differences in heart rate are the rule rather than the exception. Rated perceived exertion was close to the expected value of one-tenth of mean heart rate for the 128 N weight but considerably less for the 88 N weight. Subjects take into account more than just cardiovascular stress in judging workload, as has become clear from fuzzy set studies (Karwowski and Ayoub 1984). In this experiment, the high body part discomfort scores in the hands and arms suggest that local fatigue may have been a factor in rated exertion. In the manual materials-handling tasks studied so far, the limiting perceived discomfort appears to be in the hands and arms despite progressive refinements in handle design and placement.

The main hypotheses of the experiment were more concerned with biomechanics than with physiology. As predicted, wrist and slippage angles were very small with all but one within 7° of zero. Clearly, the handle angles derived from the earlier studies do work in a practical carton-handling task. However, the idea of the curved handle did not show any measurable improvement over straight handles. Careful review of the video tapes showed that in fact a lifting task was not the task to use to find such an effect of handle shape. In a lifting task, subjects must maintain a good grip on the handle throughout the lift. They grip both straight and curved handles near the top of the handle when lifting from floor level and are forced to maintain this hand position throughout the lift because a regrasp would interrupt the application of the upward force on the handles. In contrast, in a lowering task, a subject could slip his/her hands down the handle merely by moving the hands faster than the box is moving. In this way curved handles could be useful. A lift/lower task with a significant holding or carrying time would also give the opportunity to make use of curved handles. The fact remains, however, that in a lifting task, curved handles showed no improvement over straight handles.

A new perspective on the choice between symmetric and asymmetric handle positions is provided by the disc compressive force data. Waist height was again confirmed as the best height for manual materials handling (cf. Drury *et al.* 1983), with floor height giving mean disc compressive force values slightly above the NIOSH-recommended action limit of 350 kg (NIOSH 1981). The finding that the symmetric handle positions give lower disc compressive force values than the asymmetric positions suggests that workers choosing symmetric positions for heavy boxes at floor height (particularly 2/2) may be intuitively minimizing their exposure to risk of back injury. Differences between the handle positions were mainly due to the elbow being significantly more extended in asymmetric handle positions, with the upper hand on the upper front edge of the box. Hence the arm's centre of gravity was placed further from the trunk giving the small but significant increase in disc compressive force. Back angle did not change significantly between handle positions, although the small sample size compared with previous experiments (6 versus 30) reduced the levels of significance of this and many other factors for many of the variables.

5. Conclusions

(1) A curved handle was no better than a straight handle in a lifting task, although it could still be useful in lowering, holding and carrying tasks.
(2) The handle angles recommended in earlier papers gave low wrist and slippage angles in a box-handling task.
(3) Symmetric handle positions had a slightly lower disc compressive force than asymmetric positions, reversing the findings for perceived exertion and discomfort. Symmetric handle positions are better suited to heavier boxes, where minimizing biomechanical stress is the major consideration, while asymmetric handle positions are better suited to light and bulky boxes.

Acknowledgments

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Des études antérieures relatives aux poignées lors de la manutention bi-manuelle de caisses, ont montré que le meilleur angle pour une poignée sur une caisse varie avec la hauteur au-dessus du sol. Afin de minimiser l'adaptation entre la poignée et le poignet lorsque cette hauteur varie, on a proposé une poignée incurvée. Six ouvriers manutentionnaires ont soulevé des caisses de 9 kg et 13 kg entre un convoyeur au sol et la hauteur de la ceinture, pendant trois minutes durant lesquelles ont a analysé les angles corporels à partir d'un enregistrement sur bande vidéo. Deux positions symétriques et deux positions asymétriques des poignées ont été examinés. Les poignées, aussi bien droites qu'incurvées, ont permis un bon ajustement main-poignée, mais on n'a pas trouvé de différence significative entre les deux en ce qui concerne les variables analysées.

Vorhergehende Studien über Griffe an Kisten, die mit beiden Händen gehandhabt werden, haben gezeigt, daß der optimale Winkel für die Anordnung des Griffes an einer Kiste in Abhängigkeit von der Höhe überhalb des Bodens variiert. Um den Einfluß der Griffanordnung auf die Handgelenkstellung, die sich in den unterschiedlichen Höhen ergab, zu minimieren, wurde ein bogenförmiger Griff vorgeschlagen. Sechs Arbeiter, die manuell Materialien handhaben, hoben 9 kg und 13 kg schwere Kisten für 3 Minuten von einem Förderband am Boden auf Taillienhöhe an, dabei wurden die Körperwinkel mit Hilfe von Videoaufzeichnungen analysiert. Zwei symmetrische und zwei asymmetrische Griffanordnungen wurden getestet. Beide, gerade und bogenförmige Griffe, zeigten eine hervorragende Paßform, aber zwischen beiden ergab sich bezüglich der Ergebnisse der Messungen kein signifikanter Unterschied.

両手で箱を取り扱うための取手に関する以前の研究結果によると，箱の取手の最適な角度は床上の高さで変化する。この高さが変化すると必要になる取手と手首の調整を最小限に押えるために，曲った取手を提案した。6名の荷役作業者が床上のコンベヤーから腰の高さまで9kgと13kgの箱を持ち上げた。その時の体の角度をビデオ・テープから分析した。2つの対象的取手位置と2つの非対象的取手位置を試験した。真っ直ぐな取手と曲った取手のいずれも手に最適に合い，その他の測度では大きな相違がなかった。

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