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Hand Placement in Manual Materials Handling

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This paper reviews the use of handles on containers and manually propelled vehicles. It is concluded that handle shape and size are relatively easy to define, but placement of handles on containers represents a more difficult problem. Laboratory and field studies of hand and handle placement are reviewed with the conclusion that handles should be placed so as to give both horizontal and vertical stability, except for heavy lifting, in which a symmetrical handle placement may be preferred, as it minimizes arm forces.

INTRODUCTION

This paper concerns the design of the hand-machine interface in manual materials-handling (MMH) tasks. Handles make boxes less apt to be dropped (Rigby, 1973); they also reduce energy expenditure in MMH tasks (Garg and Saxena, 1980; Mital and Ayoub, 1981) and are associated with a lower heart rate in MMH workers (Mital and Ayoub, 1981).

When large forces must be exerted, the whole hand usually takes part by grasping a handle, an edge, or a corner of the object to be handled. Such grasps have been classified by Napier (1956) as either a power grip, if the fingers and thumb are able to flex around the handle, or a hook grip, if only the fingers take part. A third type of grasp, the precision grip, is less able to exert large forces but is beneficial in terms of control. Design of a handle or hand grip should be based upon the type of gripping action used. However, many of the handle-design parameters can be shown to be quite similar in different applications and, indeed, quite similar for different torques or forces exerted. The purpose of this review is to present the research findings on handles so that designers can produce handles that truly fit the human hand.

HANDLE SIZE

In designing handles to fit the hand, it would be logical to start with the anthropometry of the hand. For clearance dimensions, such as handle length and free space around the handle, the size of a large male hand is the appropriate design criterion. Garret's (1971) data and standard design guides (e.g., the U.S. Army design guide [HEDGE, 1974]) suggest a length of 115 mm and a clearance of from 30 to 50 mm all around the handle. The gloved hand can be accommodated by adding about 25 mm to these dimensions.

Although anthropometry is useful for clear-

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ance dimensions, it is less clear how to use anthropometry for defining an optimum handle diameter. Should fingers and thumb just meet around the handle or should some degree of overlap be provided? Is a single size of handle optimal for pushing, pulling, and turning tasks? Garret's (1971) data show that for a fifth-percentile male, the maximum diameter without appreciable overlap of fingers and thumb is 41 mm, but is this optimum in practice? Confusion is evident in guidebook recommendations. For example, HEDGE (1974) recommends a diameter of from 6 to 25 mm, depending upon weight, whereas Woodson and Conover give a 12.7- to 28.6-mm diameter for controls and a 44-mm maximum diameter for handrails. Damon, Stoudt, and McFarland (1966) give 38 mm as the maximum diameter for handles. The larger diameters may be based on anthropometric recommendations; however the lower ones must be based on different criteria for hand/handle fit.

Fortunately, there are a number of studies in the literature that measure performance (usually force exerted) or physiological cost (usually EMG) or psychophysical scale values (usually preference) for many different handle-using tasks. A review of these (Drury, 1980; Drury et al., 1982) is summarized in Table 1.

The overall pattern of these studies is somewhat confusing, but a handle diameter range of from 25 to 40 mm would cover most of the optima found in the studies. Where a hand must grip a split handle, such as a brake or clutch lever on a hand truck, the optimum distance between the grips for maximum grip strength has been measured. Greenberg and Chaffin (1979) show that for males and females of all sizes, a grip distance of 76 to 89 mm is optimal. Hertzberg (1955), in a similar study for pilots, found 64 mm better than either 38 mm or 102 mm, both with and without gloves. Gloved gripping forces were about 20% below bare-hand forces. A study by Wang, Bishu, and Rogers (1983) confirms the grip-force reduction and shows that the stiffer and bulkier the glove, the greater the loss of gripping ability.

HANDLE SHAPE

Small deviations from a cylindrical handle of constant diameter need not have a large effect on handle performance. Khalil (1973) used an elliptical handle of 41 × 31 mm cross section and a spherical handle 51 mm in diameter and found little difference between integrated EMG on these two, when compared with a cylindrical handle 51 mm in diameter. Pheasant and O'Neill (1975) com-

TABLE 1

Summary of Grip Diameter Recommendations

Authors	*Task*	*Measures*	*Optimum Diameter*
Pheasant and O'Neill (1975)	screwdriving	forces	30–50 mm
Saran (1973)	T-bar handle	preferences	25 mm
Ayoub and LoPresti (1971)	pulling	grip forces	38 mm
Khalil (1973)	pulling	EMG	32 mm
Drury (1980)	lifting	grip force	31–38 mm
Drury (1980)	holding	force duration	20 mm
Brook et al. (1974)	handrail	preferences	32 mm
Steinfeld et al. (1981)	handrail	forces	25–38 mm
Cochran and Riley (1982)	thrust	forces	28–41 mm

pared the 13 commercially available screwdriver handles with smooth and knurled cylinders of the same diameter. When the effect of handle diameter was eliminated, there was no difference between the screwdriver handles and equivalent knurled cylinders. Tichauer (1973) points out that providing finger grooves to give form-fitting handles may not be a good idea. The finger spacing of each person is different, and any design compromise on "average" spacing will be a poor fit for much of the population. Rubarth (1928), in studying shapes of screwdriver handles, found a cylindrical handle with a rounded end better, by 10 to 20% in maximum force, than more elaborately shaped handgrips.

A study of handles for exerting a thrust force on power tools by Cochran and Riley (1982) showed, in addition to the diameter effects quoted earlier, a significant effect of handle shape. Cross sections of circular, modified circular, square, rectangular, and triangular shape were tested by measuring the thrust force exertable. The best handle shape of the nine tested was triangular, but the differences in forces between that and the worst shape, circular, were only 9.3% for push forces and 7.5% for pull forces. It is debatable whether the slight increase in a force normal to the usual force exerted in manual materials handling is beneficial in light of the high point-loads associated with noncircular cross sections.

Nielson (1978) compared a wide variety of handles for their suitability in industrial tray design. He recommends handhold cutout or drawer-pull handles of generous size at both ends of the tray for carrying and low lifts, and gripping blocks 19 mm thick and from 51 to 76 mm deep if the tray must be lifted high or over a wide range. This prevents the hand from being locked into the handle and thus giving extreme ulnar deviation of the wrist when the load is lifted to high levels.

HANDLE SURFACE TEXTURE

Most authors recommend a nonslip texture for the handle surface (Nielson, 1978; Rigby, 1973; Pheasant and O'Neill, 1975), and Pheasant and O'Neill give force production data to support this recommendation. Perhaps more important is the elimination of sharp edges, corners, seams, or excessive ribbing (Nielson, 1978). A pilot study failed to show significant differences in voluntary holding time between smooth, padded, and sandpaper-textured handles. Surface texture may not be as important a variable in handle design as size and shape. It should be noted that a nonslip texture may also abrade the skin of the hands and inhibit adjustment of hand position.

HANDLE POSITIONS

The position of the hand-machine interface will be determined by the task to be performed. For example, we would expect different optimum positions for moving a box or container as compared with those used in pushing and pulling a vehicle.

For manual materials handling, an industrial survey was used to collect data on hand positions used by materials handlers on box-like objects (Drury, Law, and Pawenski, 1982). Considerable data were recorded for each of more than 2000 box movements on 27 subjects in nine industries, including parcel delivery, food warehousing, and chemical products manufacturing. Data were recorded for the subject, for the box, and for the task. Of most concern here are the findings on handle positions during the task.

The task itself was seen as having five stages:

(1) *Pregrasp*, in which the object is brought into position for picking up but the weight of the object is not yet wholly supported by the subject.
(2) *Pickup*, in which the subject first takes the full weight of the object.

(3) *Move/carry*, in which the subject supports the full weight of the object, moving it from the initial location to the final location.
(4) *Putdown*, where the weight of the object is at least partially, if not totally, relinquished.
(5) *Adjust*, in which the object is moved (usually slid) into the final position.

As pregrasp height was expected to be the same as pick-up height, and put-down height to be the same as adjust height, only three stages of the task (start, during, stop) were used to record the height of the bottom of the object from floor level. These same three points, between which the object weight is wholly supported by the subject, were used to determine how far the subject had to reach over to control the object and whether the subject was twisting or was in a sagitally symmetric condition.

Over the whole set of 2038 box-handling movements, the great majority (1827, or 90.1%) were two-handed throughout. For these two-handed movement data, there were 81 possible pairs of hand positions, but only about two-thirds of these were ever recorded. The great majority of hand-position pairs recorded were only a relative few of these 81 possibilities. For example, for the move/carry stage, 1 hand position accounted for more than 40% of the results, 2 positions for more than 50%, and 15 positions for more than 95% of the results. Manual materials handlers apparently use only a small variety of hand positions. To analyze this more carefully, the 17 most frequent hand-position pairs were tabulated at each stage of the movement using the nomenclature of Figure 1. For each pair, both left- and right-handed versions were counted together so that, for example, Position 3/7 (the most common of all stages) includes both left hand in Position 3, right hand in Position 7; and right hand in Position 3, left hand in Position 7.

Figure 2 shows the cumulative percentages of each of these 17 frequent hand positions at each stage of the movement. The two posi-

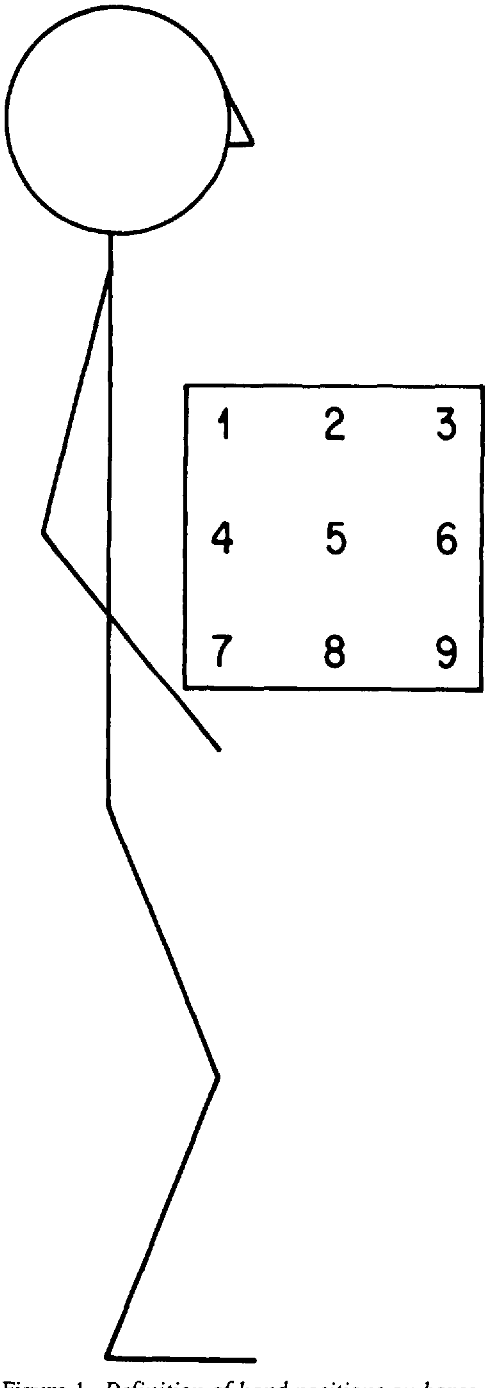

Figure 1. *Definition of hand positions on boxes.*

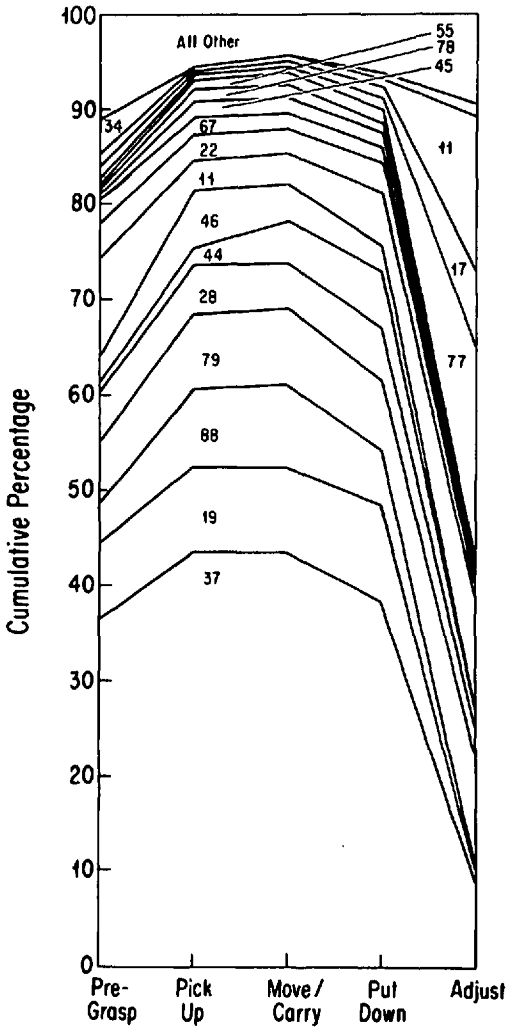

Figure 2. *Cumulative percentages of use of each hand position at each stage of box movement (from Drury, Law and Pawenski, 1982).*

tions, 3/7 and 1/9, that use hands on diagonally opposite corners of the box account for about half of all the data at all stages except for adjust. An adjust stage was only present on 15.1% of movements, but different hand positions were observed. Almost half (47%) of all adjust movements had both hands on the back edges of the box (Positions 1/7, 1/1, and 3/4). This was usually the only edge available when putting the box close to other boxes. At all stages, the "symmetrical on bottom edge" position, 8/8, was within the five most frequent hand positions, accounting for approximately 10% of the movements.

Although Figure 2 describes the overall hand-position data, it is possible to relate the hand-position behavior to other variables of the subject, the box, and the task. For example: Is 3/7 favored by taller subjects? Is position 1/9 only used for light boxes? The survey studied natural behavior and thus significant inferential statistics here indicate relationships but not necessarily causation. With this in mind, the simplest method possible was used to relate each hand position to other variables. Each variable, such as subject height or box weight, was tabulated and split as near to the median as was possible with such highly quantified data. The frequencies of movements with each hand position were counted as above or below the median on each variable. Chi-square tests were then performed to assess whether each variable was related to each hand position.

Analyses were performed separately for each stage of the lift except the adjust stage, which used different hand positions. For the remaining four stages, a high degree of agreement was found between stages, so that the results shown in Tables 2 and 3 cover significant results for all stages. Asterisks indicate the only places where a significant change of direction between stages was found. (Note: Tables 2 and 3 are not identical to those presented in Drury, Law, and Pawenski, 1982. Hand positions covering more than one number, for example on very shallow boxes, were removed prior to the analysis.)

The results are shown for subject and box variables in Table 2 and for task variables in Table 3. For each relationship, the direction is shown by the entry. For example, Position 1/9 is significantly associated with box weight (i.e., lighter boxes are more frequently

TABLE 2

Pattern of Significant Effects on Subject and Box Variables on Hand Position for First Four Stages of Lift

		Subject		Box			
Hand Position	Frequency	Height	Weight	Height	Width	Length	Weight
3/7	799	short	light	high	wide	short	heavy*
1/9	168	tall	heavy	high*		long	light
8/8	159	tall	heavy	low	narrow	long	heavy
7/9	145	short	light	low	wide	short	light
2/8	87	tall	heavy	high		long	heavy
1/3	58	tall	heavy	high	wide	long	heavy
2/2	50		heavy	high	wide	long	heavy
6/7	31	short	light		narrow	short	light

* Significant change of direction between stages.

associated with this position). Overall, box width and distance carried have the least significant effects on hand position, with all other variables showing a complex pattern of significant effects. It appears that the frequency of hand positions is greatly affected by subject size and box size. Table 3 shows generally that there are more significant relationships at the start and at mid stages of the movement than at the end, suggesting that humans determine their hand positions based on factors early in the movement rather than on factors that will be appropriate at the end.

In order to elucidate these results, two laboratory studies of handle positions on boxes need to be considered. The first (Coury and Drury, 1982) studied static holding of boxes at waist height using all 10 combinations of Handle Positions 3, 6, 8, and 9 from Figure 1. Biomechanical, physiological, and psychophysical measures, such as Borg's (1962). Rated Perceived Exertion Scale, or Corlett and Bishop's (1976) Body Part Discomfort Scale were used. The major result was that handle position had as large an effect on the measured variables as a change in box weight from 10 to 15 kg. In terms of handle positions,

TABLE 3

Pattern of Significant Effects of Task Variables on Hand Positions for First Four Stages of Lift

Hand Position	Frequency	Distance Carried	Height of Movement			Reach-Over			Biomechanical Lifting Equivalent		
			Start	Mid	End	Start	Mid	End	Start	Mid	End
3/7	799	long	high	low	low	near	far	far	diff	diff	diff
1/9	168						far	far	diff	diff*	diff*
8/8	159		high		high	near	near	near	diff	diff	easy*
7/9	145	long	high	high	high		far	far	easy	easy	easy
2/8	87	short	low*	low	low	near		near		diff	
1/3	58	short		low	low	near			diff	diff	diff
2/2	50		high	low		far	near		diff	diff	diff
6/7	31		high	low		near	near	near	easy	easy	easy

* Significant change of direction between stages.

those giving both horizontal and vertical stability (e.g., 3/8, 6/8) minimized the physiological and perceived stresses, whereas the symmetrical position at the bottom of the box (8/8) minimized hand forces.

The second study extended these results to three holding heights (floor, waist, and shoulder) and used a sample of 15 male and 15 female industrial manual materials handlers. Box size was 400 × 400 × 400 mm, and two box weights of 9 and 13 kg were chosen based on the industrial survey. Six handle positions, 1/9, 8/8, 3/7, 3/8, 6/8, and 2/2, were chosen to represent (1) the "best" from the earlier study (3/8, 6/8, 8/8), (2) very frequent ones in the survey (3/7, 1/9, 8/8), and (3) the "normal" position for handle cut-outs in cardboard containers (2/2).

Results again showed a highly significant effect of handle position on the measures tested. For the evaluative variables, Table 4 shows the relative magnitudes of the handle position effect and the container weight effect. Handle position changes were equivalent to a 30% to 60% change in container weight and hence are of major importance in manual materials handling. Particular handle positions again showed a marked superiority of the positions having both horizontal and vertical stability, 3/8 and 6/8, as shown in Figure 3 for rated perceived exertion. In most measures, except hand forces, the symmetrical positions (2/2 and 8/8) were poor choices. Figure 3 also shows that the best two positions are best at all heights.

Interrelationships between the set of 19 measured variables were explored by constructing an intercorrelation matrix using the 18 Height × Handle Position interaction (H × P) means of each variable. In all, 129 of the 171 correlation coefficients were significant at $p < 0.05$ or higher. The RPE scores and the BPD scores all intercorrelated ($r = 0.9$ or better), and all correlated negatively with hand forces ($r = -0.75$ or better). Heart rate did not correlate significantly with any of these variables. Rather than present the whole intercorrelation matrix, a factor analysis was performed on it using the principal components method with varimax rotation of factors. Three orthogonal factors accounted for 95.1% of the total variance, with the variables giving high factor loadings as follows:

(1) *Factor 1* (74.8% of variance): High rated perceived exertion, body-part discomfort frequency, body-part discomfort severity, flexed knees and waist, low force in upper hand, extended shoulder for lower hand.
(2) *Factor 2* (13.4% of variance): High force in

TABLE 4

Relative Magnitudes of Handle Position Effect and Container Weight Effect

Variable	*Handle Position Range*	*Weight (9–13 kg) Range*	*HP Range as Percentage of Weight Range*	*HP Range as Equivalent Percentage of Container Weight Change*
Force, left	1.467	1.756	84	37
Force, right	2.027	1.355	150	67
Heart rate	5.517	4.659	118	52
Body-part discomfort frequencies	0.211	0.309	68	30
Body-part discomfort severity	0.406	0.307	132	59
Rated perceived exertion	1.067	1.719	62	28

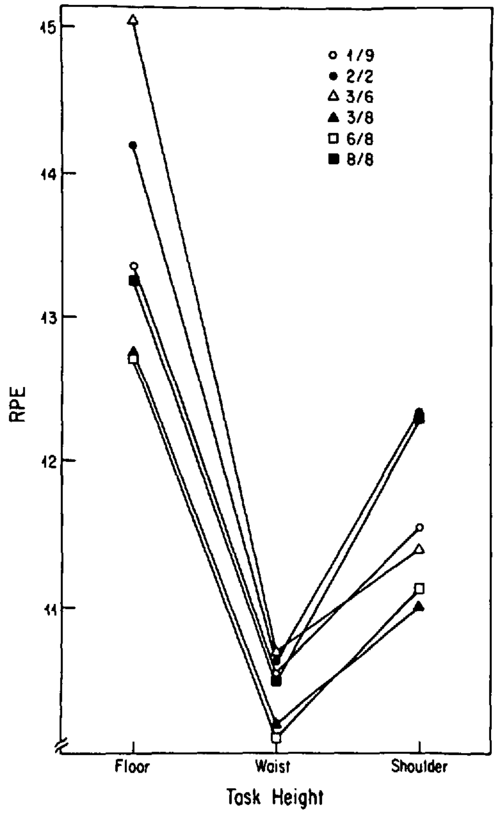

Figure 3. *Rated perceived exertion for each task height and handle position.*

lower hand, flexed shoulder for upper hand, low wrist deviation in upper hand.

(3) *Factor 3* (6.9% of variance): High heart rate, extended knees and waist, flexed elbows, vertical angles.

The first factor appears to be identified with the squatting position and, perhaps, Handle Position 3/6. The second is more difficult to interpret but appears to represent handle position 1/9. Factor 3 represents the two upright task heights.

Task height had, as expected, a very large effect on all indices. In particular, the upper limbs and the container interacted in different ways at the three heights. At the floor position, arms were extended, wrists highly deviated in the ulnar direction, and handles almost horizontal on an almost-horizontal box. All of the box weight was hung from the two hands. At the higher task heights, the box was clasped to the body with almost vertical handles on a tilted box. Wrist deviation was again present but was smaller in magnitude than was the case at the floor level. Combined hand forces were almost 50% higher than the container weight.

In both this experiment and the Coury and Drury study, the recommendations appeared to be quite general. No effects of box size or subject gender were found, nor did box weight affect the body posture. A further conclusion of the Coury and Drury study was that for static holding with a waist-high container, the body/box interface plays an important part in the MMH task. Calculated reaction forces were always larger than the container weight, while body/box friction force averaged 25% to 75% of box weight. The handles are being used to help the worker hold the box against the body and relieve the hands and arms of upward lifting forces at the expense of horizontal "hugging" forces.

By taking into consideration the results of the two laboratory studies that we have discussed, the hand-position results of the MMH survey can now be more fully interpreted. The 3/7 and 1/9 hand positions, used on more than half of all movements, fulfilled the conditions derived from the laboratory experiments, providing both horizontal and vertical stability. These two diagonally opposite hand positions took this principle as far as possible, although in the laboratory study, Position 1/9 proved to be a poor choice. Hand positions were not random, as relatively few positions accounted for the great majority of movements. Hand positions tended not to change after the pregrasp stage until the adjust stage. In this latter stage, hand positions on the subject's side of the box were favored.

Although the diagonally opposite hand positions were the most favored in both laboratory and field, Position 8/8 also rated highly in both. This position, which minimized forces on the arms in the laboratory, was also among the five most frequent positions in the survey. It was associated (Table 2) with tall, heavy people moving compact but heavy boxes. Such a "both hands under" position obviously has its specialized uses, especially on heavy boxes, where hand forces need to be minimized, and on narrow boxes, where lack of horizontal stability is relatively unimportant. The only other position associated with heavy boxes was 2/2, also a central, symmetrical position.

A low box height was associated with hand positions in the lower half of the box. Unless a box was tall, the subject was unlikely to benefit from having a steadying hand near the top. Almost the same set of hand positions was associated with narrow boxes (i.e., those that are compact fore and aft).

Task variables (Table 3) give interesting effects on hand positions. The effects due to biomechanical lifting equivalent (BLE) were quite similar to the effects due to box weight. Easy BLE values were confined to the lower half of the box, and difficult BLE values had either horizontal and vertical stability (3/7) or were centrally symmetric (2/2, 8/8, and 2/8). With the height and reach-over variables, clear patterns again emerged. First, hand position was determined more by the situation at the start of the movement and during the movement than by conditions at the end of the movement. Second, Hand Position 3/7 seemed to be associated with lowering (high to low), whereas Position 8/8 was associated with movements at the same level (high to high). High movements, and movements far from the body used low and far-back hand positions (7/9 and 4/4), whereas low movements used high hand positions 2/2 and 2/8. Movements towards the subject (far to near) tended to use 8/8, whereas movements away from the body (near to far) showed more use of 3/7. Many of these effects look "sensible" in that they extend a person's reach or introduce appropriate stability.

Manual materials handling is not just box lifting. Handle position in pushing and pulling tasks has been studied biomechanically and anthropometrically. In terms of maximum forces exerted, Kroemer (1974) showed that a bar height of from 70 to 80% of shoulder height gave maximum pushing forces and maximum efficiency of work. In terms of height above the floor, this gives a range of 860 mm to 1230 mm for 5th-percentile females to 95th-percentile males. This is in line with the usual textbook recommendation of a pushing height of "between elbow and shoulder."

It is interesting that a study of 57 pedestrian-powered vehicles in a hospital (Drury, Barnes, and Daniels, 1975) found only 37% with handles of any type. Of those with handles, 71% had handles within the 5% female to 95% male height range but only 43% had handles of a reasonable diameter (25 mm to 38 mm). The main problem with all vehicles was lack of foot space behind and under the vehicle.

Pulling forces can best be exerted at a lower height than pushing forces. For example, Ayoub and McDaniel (1974) found 40% shoulder height (490 mm to 620 mm) optimum for pulling. Snook's tables of maximum acceptable pushing and pulling forces (Snook, 1978) show that a 640-mm height was better than a higher bar height for males, and for females a 570-mm height was better than a higher bar height. This is contrasted to push forces, where 950 mm was optimum for males and 890 mm for females.

HANDLE ANGLES

The Coury and Drury (1982) laboratory study of two-handed holding used freely pivoting handles to measure the most natural angle of each handle. Not surprisingly, the handle angles measured were nearer horizontal on the bottom of the box (Position 8) but became almost vertical along the front of the box (Position 3). The actual mean handle angles to the horizontal axis of the box were Position 3, 83 deg; Position 6, 75 deg; Position 9, 65 deg; and Position 8, 55 deg.

Although these angles may be optimum for a box-holding task at waist height, Nielson (1978) points out that any changes in the height at which the box is held or moved will have a large effect on the handle angles. If the angle between the handle and the long axis of the subject's forearm is anything but 90 deg, then the wrist and hand must be angulated to accommodate the difference. The angulation is expected to be radial/ulnar deviation of the wrist, a condition with an established pathology and an association with worker complaints. Such wrist deviation was in fact discovered in the second laboratory study, and was found to average between 15 and 20 deg.

An important question is how wrist deviation can affect the manual materials handling operator. Because deviation is the accommodating mechanism between container and worker and is also potentially damaging, two experiments were conducted to quantify its effect on an MMH task. The simplest possible task, that of static holding of a container in one hand, was used to study the effect of wrist deviation. Following the lead of Coury and Drury (1982), a number of different variables (anatomical, physiological and psychophysical) were measured. A pilot study (Ulate, 1980) determined that there were observable effects.

In the main study, the subjects (15 male and 15 female manual materials-handling workers) held a compact box at their side by a single handle mounted on the top of the box. Two box weights (9 kg and 13 kg) were used in combination with five handle angles (20 deg radial, 10 deg radial, 0 deg, 10 deg ulnar, 20 deg ulnar). Subjects held the box for 25 s, rating RPE and body-part discomfort after the trial. Side-view photographs enabled the angles of the arm, the wrist, and the box to be measured. Heart rate was recorded.

An intercorrelation matrix was calculated for the 10 weight and angle combinations of eight variables measured in this study. This matrix was subjected to a factor analysis with varimax rotation to find the principal orthogonal factors in an interpretable form. Two factors emerged, the first accounting for 66.7% of the variance and the second for the remaining 33.3%. After rotation of axes, these factors showed a clear pattern. Factor 1, representing physiological costs or task difficulty, correlated at 0.912 or better with all of the physiological and psychophysical variables. Factor 2, representing angular accommodations, correlated at 0.70 or better with all of the anatomical variables. Clearly, the physiological variables are measuring a function that is optimum in the range of 0 to 10 deg ulnar. On the other hand, the anatomical variables measure accommodation of the body to handle angle and are generally linear over the range tested.

The overall effect of handle angle was significant in statistical terms and important in practical terms. Changing the handle angle from neutral to 20 deg radial produced the same size of effect as changing the box weight by an average of 16%. In many materials-handling tasks, a 16% box-weight reduction would represent a useful saving in stress on the operator. As in the pilot study, a handle angle to the ulnar side of neutral was found to be optimum, with radial handle angles producing the highest cost to the subject. An angle between the handle and the box that lies between 0 and 10 deg ulnar would seem to provide an optimum solution, representing a combination of results of both studies.

The conclusion was that in this experiment subjects allowed considerable slippage to occur at the hand/handle interface while making a minor accommodation in terms of wrist deviation, and tiny, but statistically significant, changes at elbow and box.

As in the pilot study, the pattern was one of subjects' attempting to avoid deviating their wrists, even at the added cost of not having an adequate grip. It showed that box handles must be designed with the task as well as the box in mind if poor human/equipment fit is to be avoided. Operators are sensible in avoiding wrist deviations in heavy, repetitive tasks, but the price they may be paying by choosing a higher slippage angle is poorer control over the box, with increased risk of dropping the box and damaging either the box or their own bodies.

CONCLUSIONS

Whether for moving an object, steadying an operator or controlling a machine, the requirements on the hand-machine interface are quite similar. Handles from 25 to 38 mm in diameter, 115 mm long, and with 30- to 50-mm clearance all around are favored in many different studies. Handle position is more specific to the task performed by the operator. In manual materials handling of boxes, handle positions that allow both horizontal and vertical stability should be used. This means a "diagonally opposite" hand position, such as 3/7, 3/8 or 6/8 in Figure 1. Hand positions such as 8/8 in Figure 1, where the hands are both under the box, minimize forces exerted and are used in special box movements, particularly with heavy boxes. For pushing and pulling tasks, handles should be 70% to 80% of shoulder height for pushing and 40% of shoulder height for pulling. The handle should again be of appropriate diameter and positioned so as to allow free foot movement in walking.

The practical problems of introducing handles should not be overlooked. Most of the research has concentrated on "stuck-on" handles that are outside of the envelope of the box. Such handles would need considerable rethinking of palletization systems, although for containers used in-house (e.g., kitting trays), they would pose no problems. The alternative is the cut-out handles that are already used on some shippers. Where the shipper is tightly packed with goods (e.g., boxes of cereal), then the shipper will need to be slightly over-width to enable the fingers to obtain clearance inside the cut-out hand hold. This change can be made conveniently when packages change (for example, with metrication of contents). Shippers that are not tightly packed (e.g., apples, meats) pose no problems. Shippers with custom interiors molded to protect the contents (e.g., electronic equipment) can have the cut-out and the interior protective molding designed together to provide hand clearance.

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