Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

Experiments on wrist deviation in manual materials handling

C. G. DRURY , K. BEGBIE , C. ULATE & J. M. DEEB

To cite this article: C. G. DRURY , K. BEGBIE , C. ULATE & J. M. DEEB (1985) Experiments on wrist deviation in manual materials handling, Ergonomics, 28:3, 577-589, DOI: 10.1080/00140138508963172

To link to this article: https://doi.org/10.1080/00140138508963172

Published online: 31 May 2007.

ERGONOMICS, 1985, VOL. 28, NO. 3, 577–589

Experiments on wrist deviation in manual materials handling

By C. G. DRURY, K. BEGBIE, C. ULATE and J. M. DEEB

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

One potential hazard in manual materials-handling (MMH) jobs is the wrist deviation required when a container is moved. Container handles may help control this deviation, but if container handles are to be designed to fit the operator, an evaluation of the effect of wrist deviation on MMH tasks is required. After a pilot experiment, a one-handed holding task was used to impose five wrist deviations on the subject, ranging in equal steps from 20° ulnar to 20° radial. Two weights of container (9 and 13 kg) were tested. Measurements of heart rate, psychophysical variables and angles of the hand and arm were taken on 15 male and 15 female subjects. No significant gender effects were found but changes in imposed deviation were equivalent to a 16% change in box weight. Radial deviation proved worse than ulnar deviation. The hand and arm accommodated to the imposed deviation by deviating the wrist but mainly by allowing the box handle to slip within the hand.

1. Introduction

A number of recent studies have sought to give recommendations for handles on containers to aid in manual materials-handling (MMH) tasks. An industrial survey of MMH tasks (Drury *et al.* 1982) showed few containers to have handles while a laboratory study of a container-holding task (Coury and Drury 1982) showed that handles have an effect on the biomechanical and physiological stresses arising from the task. This latter study recommended angles between box and handle, deriving these from the angles assumed by pivoting handles on the container.

However, in MMH tasks outside the laboratory, two complicating conditions are found. First, the handles do not pivot, and, second, the task is performed at a wide range of heights (see, for example, Drury *et al.* 1982). Hence, any handle angle will only be 'correct' in a single position. Away from this position the operator must accommodate to the handle by deviating the wrist and/or gripping the handle with other than the whole width of the hand.

Wrist deviation, either ulnar or radial, has an established pathology, especially when associated with repeated force exertion at large angles. Graham (1977) has reviewed inflammatory and constrictive conditions of the wrist. In particular, inflammation of tendons and tendon sheaths in the carpal tunnel can lead to constriction and entrapment of the median nerve, causing sensory deficiencies and hypersensitivity in the palm and prime digits. Tichauer (1978) states that the frictions and lateral pressures in the carpal tunnel can be kept to a minimum by keeping the wrist in a neutral position, that is by keeping the '... metacarpal bone of the ring finger reasonably parallel with the distal end of the ulna...'. Grandjean (1979) used questionnaires in studying 119 female accounting-machine operators. Tiredness and cramps in the hand were associated with ulnar deviation of the wrist.

Wrist deviation also has another effect of importance in MMH, it reduces the maximum finger and hand-grip strength as compared with a neutral wrist. Terrell and Purswell (1976) found a 15% reduction in grip strength for 20° ulnar deviation and an

18% reduction for 20° radial deviation. Pryce (1980) found no reduction for 15° ulnar deviation and a 9% reduction for 30° ulnar deviation. These results held for a 15° dorsiflected wrist or a wrist neutral in flexion/extension but a 15° volarflected wrist gave no ulnar deviation effect. However, Hazelton *et al.* (1975) found a slight *increase* in finger forces at 21° of ulnar deviation or 14° of radial deviation.

The second mechanism of accommodation, gripping the handle with less than the whole width of the hand, will result in a less secure grip. This leads to reduced control over the container and increased risk of dropping it. In addition, a poor grip of this sort reduces the contact area between the hand and the handle leading to higher local pressure on those parts of the hand still involved in the grip. Such increased pressures can be fatiguing and should be avoided (W. Nielson 1978 personal communication). Any recommendations for handle positions and handles must take into account the effects of handle deviation if they are to minimize the overall stress of MMH tasks.

Because both the accommodating mechanisms between container and worker are potentially damaging, two experiments were run to quantify its effect on an MMH task. The simplest possible task, static holding of a container in one hand, was used to study the effect of wrist deviation. The first of the two one-handed holding studies reported here (Ulate 1980) was a pilot study to determine whether any effects would be observed. The main study was part of a sequence of container-handle studies performed for the National Institute for Occupational Safety and Health.

2. Pilot study

2.1. *Methodology*

A rectangular box (425 mm long × 215 mm wide × 395 mm high) was fitted with a handle 130 mm above its upper surface. The handle had a diameter of 25 mm and was 150 mm long. The box with the handle weighed 12 kg. Nine handle angles were evaluated in 5° increments from 20° ulnar deviation to 20° radial deviation. The brief-case-type box was held for 30 s on each trial, and alternate trials were performed for the left hand and the right hand. The box was held at the subject's side with instructions for the arm to hang down in a relaxed manner. Nine student subjects ranging in age from 20 to 40 years were used. There were seven males and two females. One female was left-handed. Nine trials (with 4 min rest between trials) were conducted on each of two days. The subjects alternated between left and right hands, and the order of testing was balanced using two mirror-image Latin squares.

Three sets of measures were used: anatomical, physiological and psychophysical. Anatomical measurements were taken from side-view still photographs taken approximately halfway through each 30 s trial. Markers were positioned on the ulna over the tubercle, on the coronoid process and over the distal styloid process. Elbow angle was measured from the vertical using these markers. Markers were also positioned at the base (proximate) and distal end of the metacarpal of the ring finger. Wrist angle was measured as the difference between the ulna line and the metacarpal line. Slippage angle was measured as the difference between a line at right angles to the metacarpal line and the handle. Box angle was measured from the vertical using markers on the box. Figure 1 shows the markers and defines these angles.

Physiological measurements consisted of the change in maximum grip strength and the EMG from the finger flexor muscles: maximum grip strength was measured immediately before each trial and again after the psychophysical measures had been taken at the end of each trial, using the procedures of Caldwell *et al.* (1974). The EMG electrodes were positioned over the finger flexors. The EMG envelope measurements were noted from a strip chart recorder at 5, 10, 15, 20 and 25 s into the task and scaled as a percentage of the pre-trial maximum grip strength EMG. The EMG instrumentation is described in detail in Ulate (1980).

Psychophysical measurements consisted of Borg's (1962) Rating of Perceived Exertion (RPE) score and Corlett and Bishop's (1976) pain/discomfort scale. The RPE scores rate the difficulty of the overall task (a whole body rating of discomfort). The Corlett and Bishop scale (0–5 such that 1 = just noticeable, 3 = moderate and 5 = intolerable) was used to measure discomfort in seven body segments as follows: finger, palm, wrist forearm, upper arm, shoulder and neck. These discomfort ratings were recorded immediately after the 30 s holding task and before the second grip-strength measurement.

2.2. *Results*

Using a factorial design (9 subjects × 9 handle angles × 2 hands), analysis of variance (ANOVA) models were used to analyse the various measurements. There were five data points per cell when finger flexor EMG was used as the dependent variable and one data point per cell in all other cases. Main effects and first-order interactions were tested as fixed effects. The second-order interactions were used as a measure of residual error with 64 degrees of freedom.

2.2.1. *Change in grip strength.* The collection of the psychophysical data caused the post-exertion grip strength measurements to be delayed for as much as 1 min. As a

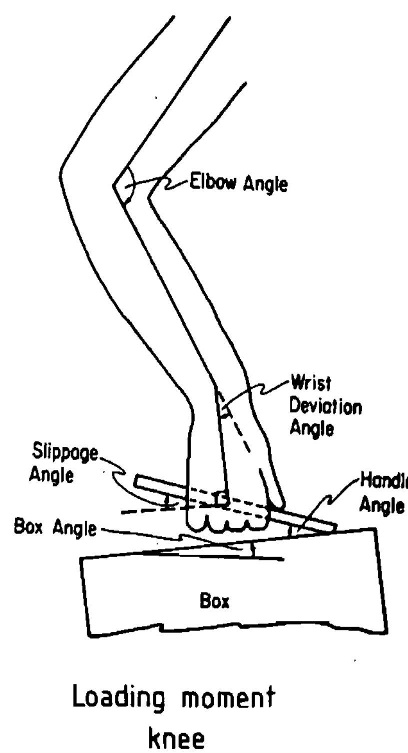

Figure 1. Definition of angles used in both studies.

result, the sensitivity of these measurements was decreased. None of the terms in the ANOVA model were statistically significant.

2.2.2. *Finger flexor EMG.* The main effects and all first-order interactions were statistically significant ($p < 0{\cdot}001$). This may be expected because there was five times as much data as for grip strength and the residual error term had 712 degrees of freedom. Percentage EMG versus handle angle is shown in figure 2. There was a large increase in the EMG measurements at extreme wrist deviations, and approximately the same EMG results were obtained at handle angles from 5° radial to 10° ulnar. The EMG results for the left hand were always higher by about 27% MVC than for the right hand, and the changes in the EMG as a function of handle angle were less pronounced for the left hand. Although statistically significant ($p < 0{\cdot}001$), the first-order interactions were very small and interpretable patterns were not noted. There was a small decrease in EMG during the course of the trial, from an average of about 28–24% MVC. This effect was consistent enough to be statistically significant in a subsidiary ANOVA ($p < 0{\cdot}001$) but no interactions were found, implying that the decrease was constant over all experimental conditions.

2.2.3. *Pain/discomfort ratings.* The mean discomfort scores were: RPE = 11·4, body part discomfort in fingers = 1·84, palm = 1·12, wrist = 0·78, forearm = 1·21, upper arm = 1·03, shoulder = 0·94 and neck = 0·66. The major discomfort was felt in the fingers and possibly the forearm. Subject effects were significant ($p < 0{\cdot}001$) in all eight models. Handle angle was significant ($p < 0{\cdot}01$) when forearm discomfort was used as the dependent variable. No other main effects or first-order interactions were significant. Forearm discomfort versus handle angle is shown in figure 3. There was an increase in discomfort at handle angles of 10° radial and 15° radial. An associated increase in discomfort was not noted at 20° radial.

2.2.4. *Anatomical measurements.* Four ANOVA's were performed using elbow angle, wrist angle, slippage angle and box angle as dependent variables. All main effects in the four models and the subject-hand interaction in three of the models were statistically

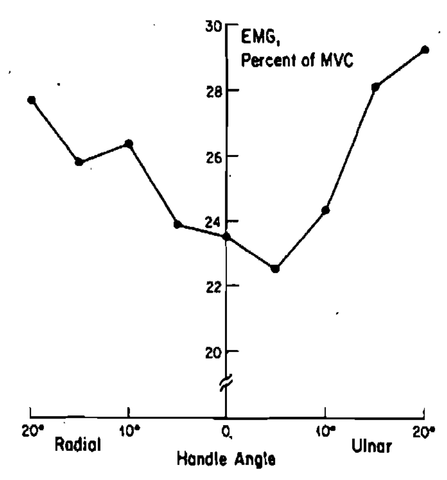

Figure 2. Effect of handle angle on finger flexor EMG, pilot study.

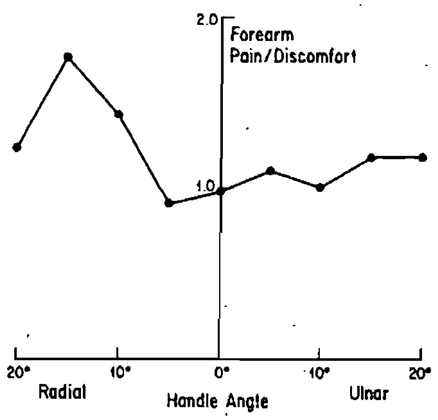

Figure 3. Effect of handle angle on pain/discomfort in the forearm, pilot study.

significant ($p<0{\cdot}01$ to $p<0{\cdot}001$). Figure 4 shows the effect of handle angle on these anatomical variables. For convenience of comparison, all four variables are plotted using the same units on horizontal and vertical scales. The relative sizes of the effects appear as different slopes of the four lines.

2.3. *Discussion*

2.3.1. *Anatomical adjustments.* Subjects reconfigure their limb segments to accommodate different handle angles. Moreover, most of the accommodation occurs at the hand. The method used to grip the handle changes significantly. Referring to figure 4 (*b*), the slippage angle changed 23° when the handle angle was varied 40° (−20° to +20°). The change in slippage angle was linear with a slope of 0·58° for every 1° change in handle angle. Secondary accommodation occurred at the wrist. There was a maximum change of 10° (−5° to +5° in figure 4 (*d*)). Based on a regression line through the data, the wrist angle changed 0·275° for every 1° change in handle angle. (If all accommodation had occurred at the wrist, the dotted line of slope 1·0 would have been obtained.) Peripheral accommodation occurred at the elbow. A maximum change of 4° (see figure 4 (*a*)) was observed; but based on a regression analysis, elbow angle only changes 0·08° per 1° change in handle angle. Although not measured in this study, there may have been residual accommodation at the shoulder.

2.3.2. *Angle of Handles.* Handle angles which require radial deviation may be more difficult to accommodate than those requiring ulnar deviation. In figure 2, the EMG begins to increase at 10° in the radial direction whereas the corresponding EMG increase in the ulnar direction did not occur until a 15° deviation was achieved. In figure 3, the highest discomfort scores were noted when radial deviation was required.

2.3.3. *Wrist deviation.* The wrist can be deviated at least 20 or 30° (Newmeyer and Kilgore 1977). The present subjects avoided such extreme deviation and tried to use a neutral position. In figure 4 (*d*), the maximum deviations are ±5°. This suggests that moderately small deviations from the neutral position may be detrimental. If a neutral zone exists, it may be relatively narrow.

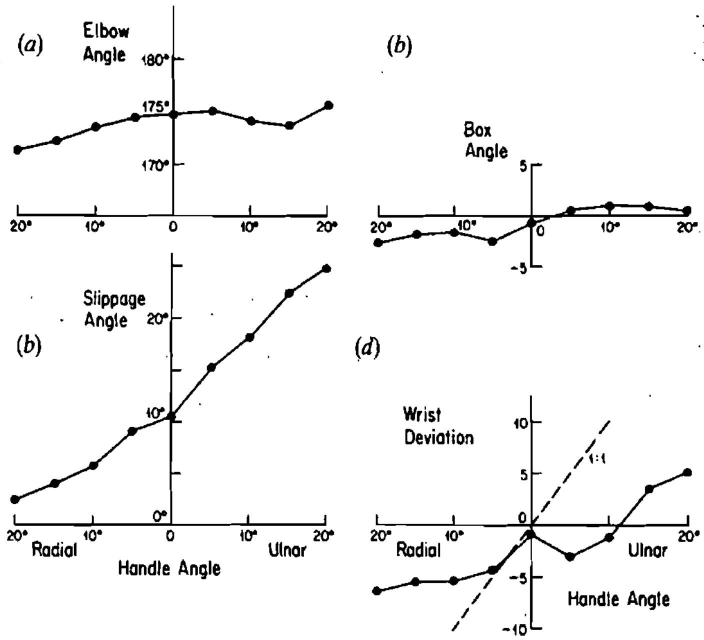

Figure 4. Changes in the four anatomical variables with handle angle, pilot study.

3. Main experiment

While the pilot study showed that subjects found wrist deviations somewhat stressful and accommodated for these deviations in a variety of ways, it did not provide the data needed to quantify the effect of wrist deviation on MMH tasks. The task was of a long duration compared with those found in the Drury *et al.* (1982) survey but was performed at only a single container weight. Both Coury and Drury (1982) and Garg and Saxena (1980) used different container weights and were thus able to express the effects of handle changes in terms of the equivalent container-weight change needed to produce the same effect. A second improvement needed to make more valid recommendations is the use of a more representative subject population. Hence, the pilot study was modified to include both these changes.

3.1. *Methodology*

The same box and static holding tests as used in the pilot study were again employed. However, only five handle angles (20° ulnar, 10° ulnar, 0°, 10° radial and 20° radial) were used. The holding duration was reduced to 25 s from 30 s, and a 95 s rest period was standardized between trials. Thirty subjects were used, 15 male and 15 female industrial manual materials-handling workers. Table 1 provides data on the subjects. (All subjects had completed a two-handed box-holding experiment prior to this experiment. A 30 min rest break separated the two experiments.)

The box weights of 9 and 13 kg (including handle weights) were used so that any handle angle effects could be compared directly to the effects of a known change in container weight.

Table 1. Subject characteristics.

Statistic	Male				Female			
	Minimum	Mean	S.D.	Maximum	Minimum	Mean	S.D.	Maximum
Age (years)	19	23·5	3·20	30	16	25·9	9·73	57
Height (m)	1·70	1·80	0·064	1·96	1·57	1·66	0·053	1·75
Weight (kg)	70	78·7	9·39	108	51	64·3	10·16	90
Job experience (months)	1	25·3	29·15	120	1	28·8	38·05	120

The dependent variables were changed to give the same set as used in an earlier two-handed box-holding experiment reported in Coury and Drury (1982). The physiological and psychophysical variables were as follows:

(1) Heart rate—measured from a continuous recording on a Grass strip chart recorder. The mean over the last 10 s of the 25 s exertion was measured.
(2) RPE—Borg's scale of Rated Perceived Exertion (Borg 1962) measured immediately after the exertion.
(3) Body part discomfort frequency—the frequency of all non-zero ratings on the Corlett and Bishop (1976) scale using the same body parts as in their paper (neck, shoulders, upper arms, lower arms, hand, upper back, mid back, lower back, buttocks, thighs and legs).
(4) Body part discomfort severity—the mean value of all non-zero ratings on the Corlett and Bishop scale. The body part discomfort ratings were changed to conform to Corlett and Bishop's original paper and analysed into frequency and severity to provide a comparison with Coury and Drury (1982) and the two-handed holding task performed on the same subjects who participated in the present experiment.

The same anatomical variables as in the pilot experiment were again measured.

Analyses of variance were performed on each dependent measure. With so many dependent measures needing interpretation, an intercorrelation matrix was calculated for the ten weight and angle combinations for the 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. Factor analysis suggests a set of orthogonal factors (i.e. uncorrelated with each other) which can be used as new and more meaningful variables. The varimax rotation rotates these (n) factors in their n-dimensional space until the original variables correlate either very highly or hardly at all with these factors. In this way the interpretation of the factors in terms of the original variables is made easier.

3.2. *Results*

3.2.1. *Physiological and psychophysical variables.* Analyses of variance of the physiological and psychophysical variables showed that the weight of the box was significant on all measures ($p < 0.001$) and the angle of the handle significant on all except heart rate ($p < 0.05$). To evaluate the practical significance of the handle-angle effect, table 2 shows the relative magnitudes of the weight and handle effects for each variable. The size of the weight effect was measured by the difference (for each variable) between the highest value (at 13 kg) and the lowest value (at 9 kg). Similarly, the size of the handle-angle effect was measured by the range (for each variable) from the best to worst angle. In the final column of table 2, the range of handle-angle effect is expressed as the equivalent weight change which would be needed on a 9 kg box to give the same change in each variable as was actually measured by the handle-angle range. The difference between extreme handle angles is about a half to a quarter as large as the difference between a 9 and a 13 kg weight of box, making the handle-angle effect equivalent to a 10–20% change in box weight. The effect of handle angle on the three psychophysical measures is shown in figure 5. The general conclusion is that 20° radial is the worst condition.

All the other effects were statistically small. The gender × weight interactions for RPE and BPD severity ($p < 0.05$) showed that females felt relatively more highly

Table 2. Relative magnitudes of handle-position effect and container-weight effect.

Variable	Weight (9–13 kg) range	Handle-angle range	Angle range as equivalent percentage of container-weight change
Heart rate	2·103*	0·725	15
RPE	2·323	0·600	12
BPD frequency	0·457	0·217	21
BPD severity	0·547	0·206	17

* All *except* this value are significant at $p < 0.05$.

stressed than males at the larger box weight. The gender × weight × angle effect on heart rate ($p < 0.05$) revealed no interpretable pattern except that the mean heart rate for females at a 20° radial angle with the 13 kg box was about 2 beats/min higher than might be predicted based on the other three gender–weight combinations.

Body part discomfort scores could be combined to give overall frequency and severity, but there were too few non-zero ratings to perform analyses of variance on each body part separately. Hence, only totals over the whole experiment are shown in table 3.

The major discomfort, on both measures, started with the hand and generally decreased up the limb to the shoulder and neck. Back discomfort was mainly lower back, and there were almost no instances of discomfort below the waist.

3.2.2. *Anatomical variables.* The analyses of variance of the four angles measured showed that handle angle was significant on all measures ($p < 0.01$), with main effects of hand ($p < 0.001$) and the hand × angle interaction ($p < 0.05$) for elbow and slippage angles. The effects of handle angle on each measure are shown in figure 6. The two largest effects were for slippage angle and wrist deviation, again as found in the pilot study. Other significant effects in the analyses of variance (weight × handle angle and gender × weight × handle angle, $p < 0.05$) were small in practical terms when compared with the accommodations at wrist and hand to box angle changes.

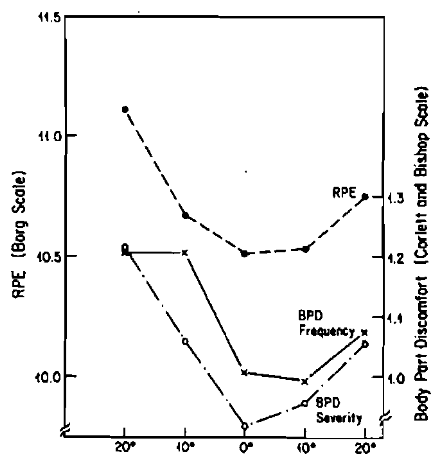

Figure 5. Effects of handle angle on psychophysical variables, main study.

Table 3. Body part discomfort at each location. (Frequency is the percentage of non-zero readings; severity is the average scale values of all non-zero readings.)

Body part location	Frequency	Severity
Upper limbs		
Shoulders	8·4	1·73
Upper arms	9·3	1·97
Lower arms	10·5	2·04
Hands	15·6	2·31
Trunk		
Neck	3·3	1·66
Upper back	0·9	0·32
Middle back	1·8	1·20
Lower back	3·8	1·64
Buttocks	0·4	0·35
Lower limbs		
Thighs	0	0
Lower legs	0·1	0·05

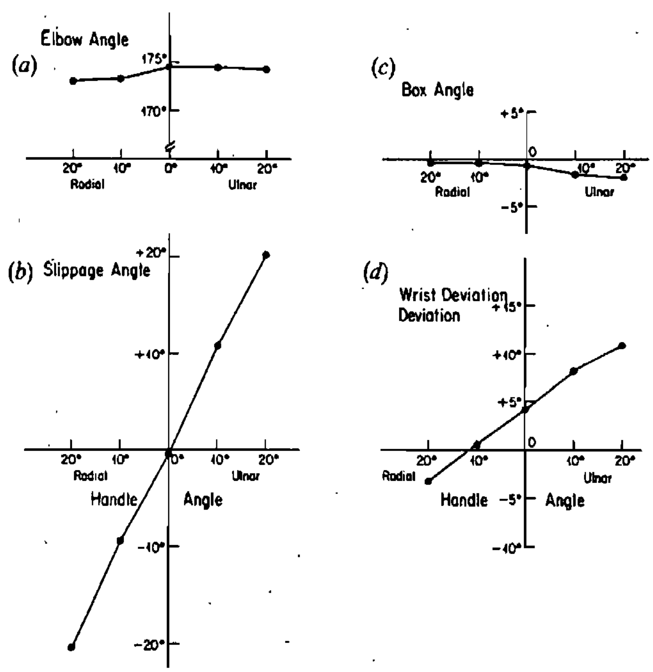

Figure 6. Changes in the four anatomical variables with handle angle, main study.

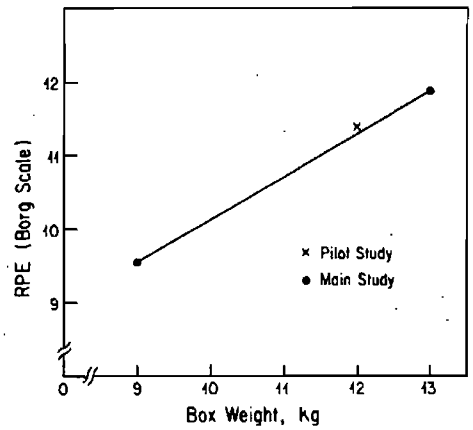

Figure 7. Comparison of effects of box weight on RPE score between main and pilot studies.

The patterns of the handle-angle effect shown in figures 5 and 6 are clearly different. Anatomical measures change in a linear manner whereas the psychophysical measures show a definite optimum region. The factor-analysis results showed this effect very clearly.

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 task costs or difficulty, correlated at 0·92 or better with all the psychophysical variables and heart rate. Factor 2, representing angular accommodations, correlated at 0·70 or better with all the anatomical variables. Clearly, the task cost variables (including heart rate which did not show a significant handle-angle effect) are measuring a function which is optimum in the range of 0–10° ulnar. On the other hand, the anatomical variables measure accommodation of the body to handle angle and are generally linear over the range tested.

3.3. *Discussion*

The overall effect of handle angle was significant in statistical terms and important in practical terms. Changing the handle angle from neutral to 20° 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 of handle to box between neutral and 10° ulnar would seem to represent an optimum combining the results of both studies.

An interesting point of comparison between the two studies is provided by the RPE score (body part discomfort was measured differently in the two studies and is not directly comparable). Figure 7 shows the effect of box weight on RPE from both studies: despite differences in subjects and experimental design, the results agree remarkably well, providing a little additional evidence for the utility of Borg's scale in even a static holding task.

The form of the anatomical accommodation between the pilot and main studies was similar but not identical. Slippage angle still accounted for the largest portion of the accommodation with wrist deviation next. Box angle and elbow angle again had very small effects. The conclusion is 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 the elbow and box. Wrist deviations actually measured (5° radial to 10° ulnar) are smaller than those implicated in repetitive trauma disorder studies. Any larger deviations would be expected to decrease the maximum grip strength available and hence, for a given required grip force, require a larger proportion of the worker's strength. The marginal effect of EMG in the pilot study and the lack of a grip-strength reduction strengthens the conclusion that wrist deviation was small.

Again 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.

4. Conclusions

1. Handle deviation has a considerable effect on the cost to the worker of a MMH task.
2. Subjects accommodate to handle deviation primarily by allowing the handle to be gripped by only part of their hand. This can decrease the effectiveness of the handle/hand interface. Wrist deviation is kept to small values of about 5° radial to 10° ulnar, values unlikely to cause pathological problems.
3. A handle angle from 0 to 10° ulnar is probably optimum for this task.

Acknowledgments

This study was supported by the National Institute for Occupational Safety and Health, Division of Safety Research. The NIOSH project officer was T. Pizatella. The authors also wish to acknowledge the assistance of Dr. R. K. Schutz who reviewed the pilot study and contributed much to the final form in which it is presented here.

Lors de la manutention de matériels lourds, l'individu peut être exposé à des déviations du poignet potentiellement dangereuses. Les poignées sur les conteneurs permettent un contrôle de l'ampleur de la déviation; mais si elles doivent être adaptées à l'opérateur, il est nécessaire d'évaluer l'effet de tâches de manutention sur la déviation du poignet. Après une expérience pilote, une tâche unimanuelle de portage a été utilisée pour induire cinq déviations différentes allant, de manière équidistante, de 20° cubitale à 20° radiale. Deux masses (9 kg et 13 kg) de conteneurs ont été évaluées. La fréquence cardiaque, diverses variables psychophysiques ainsi que les angles des mains et bras ont été relevés auprès de 15 sujets hommes et 15 sujets femmes. On n'a pas observé d'effet du sexe mais les variations dans les déviations imposées étaient équivalentes à une variation de 16% de la masse des caisses. La déviation radiale semble être plus préjudiciable que la déviation cubitale. La main et le bras s'ajustent à la déviation imposée en déviant le poignet, mais surtout en permettant aux poignées de glisser dans la main.

Ein potentielles Risiko bei Arbeiten, die aus dem manuellen Bewegen von Material (MMH) bestehen ist die Abweichung des Handgelenks, die hervorgerufen wird, wenn ein Behälter bewegt wird. Griffe an Behältern können helfen, diese Abweichung zu kontrollieren, aber wenn Griffe von Behältern gestaltet werden müssen, die an den Bediener angepasst sein sollen, ist eine Untersuchung der Auswirkung der Handgelenkabweichung auf MMH Aufgaben notwendig.

Nach einer Pilotuntersuchung wurde eine einhändige Halteaufgabe verwendet um 5 Winkelabweichungen des Handgelenks vorzugeben, in gleichen Schritten von 20° ulnar bis 20° radial. Es wurden zwei Behältergewichte (9 kg und 13 kg) untersucht. An 15 männlichen und 15 weiblichen Personen wurden Messungen der Herzschlag. frequenz, psychophysikalischer Variablen und Winkeln von Arm und Hand vorgenommen. Es konnten keine signifikanten Einflüsse aufgrund des Geschlechts ermittelt werden, die ermittelten Änderungen der vorgegebenen Abweichungen waren der 16 prozentigen Gewichtsänderung äquivalent. Radiale Abweichung wurde als ungünstiger angesehen, als ulnare Abweichung. Hand und Arm passten sich der aufgezwungenen Abweichung an, indem das Handgelenk ausgelenkt wurde, aber hauptsächlich durch das Gleitenlassen des Behälters in der Hand.

荷物取扱い作業（MMH）時の潜在的な災害の一つに容器を移動させる時の手首の偏位がある。容器の取っ手はこの偏位の制御を助けるが，取っ手を作業者に合う様に設計するつもりであれば，荷物取扱い作業に及ぼす手首の偏位の影響を評価する必要がある。予備実験の後，被験者に片手保持作業を行わせ，尺側20°から撓側20°まで均等な間隔で5種の手首の偏位を課した。容器の重量は9 kgと13kgで実験を行った。男性及び女性被験者15名ずつにつき，心拍数，精神物理学的変数，そして手と上腕の角度の測定を行った。有意な性差は見られなかったが，偏位を課した場合の変化は箱の重量の16%の変化と等価であった。尺側の偏位よりも撓側の偏位の方が成績が悪かった。手と上腕は課せられた偏位に対し手首を回転させて対処するが，ほとんどの場合は手の中で箱の取っ手をずらすことによって行う。

References

Borg, G. A. V., 1962, *Physical Performance and Perceived Exertion* (Copenhagen: Ejnar Munksgaard).

Caldwell, L. S., Chaffin, D. B., Dukes-Dobos, F. N., Kroemer, K. H. E., Laubach, L. L., Snook, S. M., and Wassermann, D. E., 1974, A proposed standard procedure for static muscle strength testing. *American Industrial Hygiene Association Journal*, **35**, 201–206.

Corlett, E. N., and Bishop, R. P., 1976, A technique for assessing postural discomfort. *Ergonomics*, **19**, 175–182.

Coury, B. G., and Drury, C. G., 1982, Optimum handle positions in a box-holding task. *Ergonomics*, **25**, 645–662.

Drury, C. G., Law, C. H., and Pawenski, C. S., 1982, A survey of industrial box handling. *Human Factors*, **24**, 553–565.

Garg, A., and Saxena, U., 1980, Container characteristics and maximum acceptable weight of lift. *Human Factors*, **22**, 487–496.

Graham, W. P., 1977, Non-specific inflammatory and constrictive conditions. In *The Hand* (edited by E. S. Kilgore and W. P. Graham) (Philadelphia: Lea & Febiger).

Grandjean, E., 1979, Pyschological and physiological reactions associated with repetitive tasks. Paper presented at the 23rd Annual Meeting of the Human Factors Society, Boston.

Hazelton, F., Smidt, G., Flatt, A., and Stephens, R., 1975, The influence of writ position on the force produced by the finger flexors. *Journal of Biomechanics*, **8**, 301–306.

Newmeyer, W. L., and Kilgore, E. S., 1977, Reports and methods to evaluate impairment. In *The Hand* (Edited by E. S. Kilgore and W. P. Graham) (Philadelphia: Lea & Febiger).

Pryce, J., 1980, The wrist postion between neutral and ulnar deviation that facilitates the maximum power grip strength. *Journal of Biomechanics*, **13**, 505–511.

Terrell, R., and Purswell, J., 1976, The influence of forearm and wrist orientation on static grip strength as a design criterion for hand tools. *Proceedings of the International Ergonomics Association*, IEA College Park, Maryland, pp. 28–32.

Tichauer, E. R., 1978, *The Biomechanical Basis of Ergonomics* (Chichester, Brisbane, Toronto: Wiley).

Ulate, C. H., 1980, Ulnar and radial wrist deviations in a one-handed static holding task. Unpublished M.Sc. thesis, SUNY at Buffalo, Buffalo, New York.

Manuscript received 18 February 1984.
Revised manuscript received 4 May 1984.