Revista Brasileira de Fisioterapia
ISSN: 1413-3555
rbfisio@ufscar.br
Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia
Brasil

Silva, Luciana C. C. B.; Oliveira, Ana B.; Silva, Danilo C.; Paschoarelli, Luis C.; Coury, Helenice J. C. G.

30o inclination in handles of plastic boxes can reduce postural and muscular workload during handling

Revista Brasileira de Fisioterapia, vol. 17, núm. 3, mayo-junio, 2013, pp. 307-318
Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia
São Carlos, Brasil

original article

Brazilian Journal of Physical Therapy

30º inclination in handles of plastic boxes can reduce postural and muscular workload during handling

Luciana C. C. B. Silva[1], Ana B. Oliveira[1], Danilo C. Silva[2], Luis C. Paschoarelli[2], Helenice J. C. G. Coury[1]

ABSTRACT | **Background:** The handling of materials, which occurs in the industrial sector, is associated with lesions on the lumbar spine and in the upper limbs. Inserting handles in industrial boxes is a way to reduce work-related risks. Although the position and angle of the handles are significant factors in comfort and safety during handling, these factors have rarely been studied objectively. **Objective:** To compare the handling of a commercial box and prototypes with handles and to evaluate the effects on upper limb posture, muscle electrical activity, and perceived acceptability using different grips while handling materials from different heights. **Method:** Thirty-seven healthy volunteers evaluated the handles of prototypes that allowed for changes in position (top and bottom) and angle (0°, 15°, and 30°). Wrist, elbow, and shoulder movements were evaluated using electrogoniometry and inclinometry. The muscle electrical activity in the wrist extensors, biceps brachii, and the upper portion of the trapezius was measured using a portable electromyographer. The recorded data on muscle movements and electrical activity were synchronized. Subjective evaluations of acceptability were evaluated using a visual analog scale. **Results and Conclusions:** The prototypes with handles at a 30° angle produced the highest acceptability ratings, more neutral wrist positions, lower levels of electromyographic activity for the upper trapezius, and lower elevation angles for the arms. The different measurement methods were complementary in evaluating the upper limbs during handling.

Keywords: ergonomic design; usability; electrogoniometry; electromyography; grip perception.

HOW TO CITE THIS ARTICLE

Silva LCCB, Oliveira AB, Silva DC, Paschoarelli LC, Coury HJCG. 30° inclination in handles of plastic boxes can reduce postural and muscular workload during handling. Braz J Phys Ther. 2013 May-June; 17(3):307-318. http://dx.doi.org/10.1590/S1413-35552012005000095

Introduction

Handling materials occurs in industrial sectors and during activities of daily living. This activity is considered to cause most of the health-related costs and problems in work environments[1].

Preventative studies have evaluated the lumbar spine during handling activities[2] at the expense of the upper limbs, even though the upper limbs are the second-most commonly affected region of the body when musculoskeletal disorders occur while performing handling activities[3-5].

Inserting handles on boxes is one way to reduce occupational risks and increase safety during handling[6]. Handles provide greater comfort and efficiency[7,8] and increase the maximum acceptable weight during handling[9]. However, the positioning of handles, which is a fundamental factor that has a great influence on the variables mentioned[7], has not been thoroughly studied in an objective manner.

Drury et al.[10] evaluated the use of handles during actual handling activities and found that inserting lateral handles close to the top and bottom surfaces of the boxes resulted in lower levels of discomfort, especially for heavy loads (13 kg). Chung and Wang[11] evaluated two types of boxes with handles and found that handles with a 0° horizontal incline caused a large ulnar deviation of the wrist, whereas the box with 90° handles caused a large radial deviation. The authors suggested that box handles should be positioned at an angle between 30º and 45° so that the wrists could remain in a more neutral position during handling. Similarly, Wang et al.[12] evaluated the effects of handle angles in relation to the maximum acceptable weight for handling and wrist deviation.

[1] Department of Physical Therapy, Universidade Federal de São Carlos (UFSCar), São Carlos, State of São Paulo (SP), Brazil
[2] Department of Industrial Design, School of Architecture, Art and Communication, Universidade Estadual Paulista (UNESP), Bauru, SP, Brazil
Received: 07/12/2012 Revised: 11/12/2012 Accepted: 12/18/2012

These authors also recommended an angle between 30° and 45° to provide a better grip.

To evaluate the benefits of an ergonomic intervention, objective quantitative measures obtained simultaneously are required to evaluate the workload imposed when performing occupational activities[13]. Although studies have evaluated the position and angle of handles on industrial boxes[7,11], only wrist movements were directly evaluated, indicating that there is also a need to evaluate other upper limb joints such as the elbows and shoulders. It is equally important that muscle activity, a significant biomechanical parameter, be evaluated, preferably in records obtained simultaneously.

Given the lack of studies that address the workload for the upper limbs during handling and the need for new box and handle designs that provide a better grip, the goal of this study was to compare the handling experience using a commercial box and prototypes. Both boxes were made from plastic material and developed especially for this study. The present study also aimed to evaluate the effects on upper limb posture, muscle electrical activity, and the perceived acceptability of different grip angles during simulated handling activities at different heights. The prototypes included handles that changed in position (top and bottom) and angle (0°, 15°, and 30°) with respect to the horizontal plane.

Method

Subjects

A sample calculation was made using the ENE software (V.2.0) to determine the number of subjects needed. To perform the calculation, the parameters for shoulder abduction were used with statistical power of 80%, a standard deviation of 14.50°, and between-group difference of 10°. Because the calculation showed that 34 subjects were needed for a sufficient sample, 40 male students were initially recruited.

The following inclusion criteria were used for the subjects: right-handedness, height between 1.65 and 1.75 m, and maximum body mass index of 29.9 kg/m^2. The goal of subject recruitment was to obtain a homogeneous sample of individuals who were inexperienced with handling activities so that the study would not be influenced by prior training. Three students were excluded from the sample because they displayed one or more of the exclusion criteria: musculoskeletal symptoms, intolerance of palpation, skin lesions, general illness, or balance problems. The level of physical activity was evaluated, and the subjects who were considered athletes were also excluded.

The participants had an average age of 23.85±3.97 years, an average height of 1.71±0.03 m, and an average weight of 73.95±10.35 kg. This age group was chosen because it is included in the largest economically active group (20 to 29 years of age) in Brazil as of 2009[14].

The subjects were informed about the collection procedures and signed a free and informed consent form, which was approved by the Ethics Committee of the Universidade Federal de São Carlos - UFSCar, São Carlos, state of São Paulo (SP), Brazil under protocol number CAAE: 0054.0.135.000-07.

Plastic boxes and evaluated handles

A plastic box (55.5 × 36 × 31 cm) was designed especially for this study (Figure 1 – B.1 and C.1). The prototype had handles (13 × 4.5 cm) that could change position (top and bottom) on each side of the box and allowed for several different angles from the horizontal plane (0°, 15° and 30°), for a total of seven different box conditions: 1) A: regular commercial

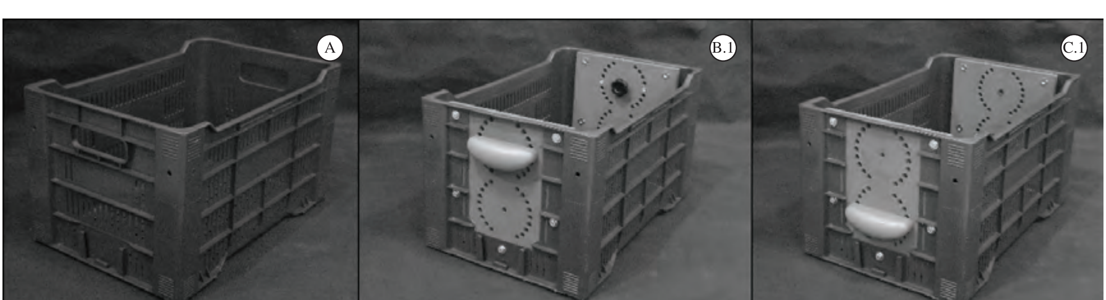


Figure 1. The boxes used in the data collection: A = regular commercial plastic box; B.1 = prototype with handles in the high position at a 0° angle from the horizontal plane; C.1 = prototype with handles in the low position at a 0° angle from the horizontal plane.

box; 2) B.1: prototype with handles at the top at a 0° angle; 3) B.2: prototype with handles at the top at a 15° angle; 4) B.3: prototype with handles at the top at a 30° angle; 5) C.1: prototype with handles at the bottom at a 0° angle; 6) C.2: prototype with handles at the bottom at a 15° angle; 7) C.3: prototype with handles at the bottom at a 30° angle. The handle inclinations were performed towards the radial deviation of the wrist.

All of the boxes had a total mass of 15 kg, determined by previous studies[15]. The handles/grips were developed from polyester resin composites with calcium carbonate.

Handling activity

The boxes were moved between three surfaces: a fixed surface (FS) 102.5 cm above the ground, the ground (G), and an adjustable surface (AS). The adjustable surface was positioned in two ways: at the height of the greater trochanter of the right femur (GT) and at the height of the right acromion (A) of each of the subjects with respect to the ground. The fixed and adjustable surfaces were positioned perpendicular to each other. The complete task involved moving the box between the following positions: FS-G, FS-GT, and FS-A. The order in which the boxes were used for each of the surface heights was randomized. Each box was moved between each surface only once.

During the procedure, synchronized records were obtained by performing electromyography, inclinometry, and electrogoniometry of the upper limbs. After moving each box, the subject responded to a subjective scale to evaluate its acceptability[16].

This study was conducted under the same experimental conditions as another study that evaluated cardboard boxes used by a local business[17]. Thus, although the goals and results of the two studies are completely different, certain aspects of the design and procedure were similar.

Record of muscle electrical activity of upper limbs

Active electrodes for surface electromyography (Model #DE-2.3, *DelSys*®, Boston, USA) were used to capture the bilateral electromyographic activity (EMG) of the extensor muscles in the wrist, the biceps brachii, and the descending portion of the trapezius. The electrodes were attached to the skin with double-sided tape (*DelSys*®).

The electrodes had the following characteristics: two parallel silver bars (1 mm^2 x 1 cm) with an inter-electrode distance of 1 cm; Common Mode Rejection Ratio (CMRR) >92 dB; input impedance >1015Ω in parallel with 0.2 pF; voltage gain of 10 V/V ±1%; and noise of 1.5 μV (root mean square, RMS).

A self-adhesive reference electrode (5 x 5 cm) was also attached to the flexor surface of the right distal wrist. The rest signal was obtained while the subject stood with relaxed upper limbs for 30 seconds.

The signal conditioner (*Myomonitor IV Wireless EMG System, DelSys*®), with a bandwidth of 20–450 Hz and noise ≤1.2 μV (RMS), improved the signals by 1000 V/V. The data sampling rate was 1000 Hz.

Before attaching the active electrodes, the skin under the electrodes was shaved and cleaned with alcohol. For the wrist extensors, the subject was asked to contract the forearm in the pronated position, enabling the palpation and identification of the muscle[18]. For the biceps brachii, the electrodes were attached at a third of the distance between the cubital fossa and the acromion[19]. For the descending portion of the trapezius muscle, the midpoint between the spinous process of the seventh cervical vertebra and the acromion was located, and the sensor was attached 2 cm laterally from this point[20].

The signals were normalized using the maximum electrical activity obtained in two maximal voluntary isometric contractions (MVICs) of 5 seconds each. The MVICs of the extensor muscles, the biceps brachii, and the trapezius were registered using the procedure described by Akesson et al.[21] and Freriks and Hermens[19]. The examiner provided verbal feedback while recording the MVICs.

Recording arm-lifting movements

To record arm-lifting motions, digital inclinometry (INC) sensors were used (*Logger Teknologi HB, Akarp, Sweden*). The accuracy and reliability of the sensors were 1.3° and 0.2°, respectively[22]. The acquisition frequency was 20 Hz.

The inclinometers were fixed below the deltoid muscle insertion using plastic plates because of the bulging in the region. The subject was asked to hold a weight of 2 kg vertically above the ground to record the reference position of the upper limbs[23]. The arms were elevated in the scapular plane to record the direction of the movement[23].

Recording elbow and wrist movements

Electrogoniometers, models SG65 and SG110 (*Biometrics®, Gwent, UK)*, were used to record wrist movements (flexion(+)/extension(–) and ulnar(+)/radial(–) deviation) and elbow movements (flexion(+)), respectively. The acquisition unit DataLog (*Biometrics®, Gwent, UK*) was used for recording and the storing data from the electrogoniometer (EGM).

The sensors were attached to the wrist and elbow joints according to the instructions provided by the manufacturer (*Biometrics®, Gwent, UK*). The maximum error measured by the sensors in a test conducted prior to the data collection aligned with the manufacturer's recommendations[24]. The acquisition frequency was 20 Hz.

To analyze the recorded wrist movements, the subject maintained a neutral wrist position for one minute. The subject was asked to remain standing with elbows flexed at 90°, pronated forearms resting on a flat surface and hands in a neutral position. The neutral position of the elbows was recorded while the subject kept the elbows fully extended with palms facing the body for one minute.

Evaluation of acceptability

After handling each box at each height, the subject responded to a subjective acceptability scale. Using this scale, which consisted of a 100-mm horizontal line, the subject evaluated the contact between his hand and the new handle configurations. The anchors "lack of acceptability" (associated with a value of zero) and "maximum acceptability" (associated with the value of 10) were located at the left and right ends of the horizontal line, respectively[16].

Data processing and analysis

The data from the EMG, INC, and EGM were processed using routines developed in *MatLab®* (version 7.0.1, *MathWorks Inc., Natick, USA*). The *Butterworth* filter with zero phase delay was used to filter all of the signals, and the design and cutoff frequency were defined for each signal.

The EMG data were filtered by a 20-450 Hz fourth-order band-pass filter, and the RMS was obtained by windowing (with a 25-millisecond duration and 50% overlap). The maximum RMS value was identified in the central portion (discarding the first and last second of collection) of the MVIC for each muscle to normalize the signal. The 30-second average RMS was calculated and subtracted from the baseline recording to correct for possible noise.

The inclinometry data were processed to identify the reference positions, the direction of movement,[22] and the elevation angles for the shoulders. Next, both the INC and the EGM data were filtered by a second-order low-pass filter with cutoff frequencies of 3 and 5 Hz, respectively. A residual analysis was performed to determine the cut-off frequencies. The average values obtained from the recordings of the neutral wrist and elbow positions were subtracted from the data collected during the box handling task.

An amplitude probability distribution function (APDF) analysis was conducted on the EMG and the movement (INC and EGM) data. The APDF is widely used to describe occupational workloads[25] based on EMG and movement records[26]. This type of analysis was considered appropriate because the average value obtained for these signals had low representativeness.

The normality and homoscedasticity of the data were analyzed using the Shapiro-Wilks and Levene's tests, respectively. Because the assumptions were not met, the EMG, INC, and EGM results and the scores on the subjective acceptability scale were compared for each of the boxes at each handling height using the Kruskal-Wallis test ($P \leq 0.05$) and the post-hoc Mann-Whitney test with the Bonferroni correction ($P \leq 0.002$). The statistical analyses were conducted using SPSS 11.5 (SPSS Inc., Chicago, IL, USA).

The postures and movements of the joints were analyzed according to the preventative guidelines and reference values described in the literature[16].

Results

Records of muscle electrical activity for the upper limbs

The average values and standard deviations of surface muscle activity (EMG), as well as the significant differences, are shown in Table 1 by muscle group. The 90th percentiles are shown because they represent the greatest muscle workload.

The lowest percentage values for the EMG in the trapezius muscle tended to occur when the subjects moved the C3 prototypes both to/from the low surfaces (FS-G) and high surfaces (FS-A). The values were high between the intermediate surfaces (FS-GT) for all of the boxes, but they were slightly lower for the B3 prototype. Regarding the muscle activity of the

Table 1. Means and standard deviations (±SD) for right (R) and left (L) EMG of the biceps brachii (90th biceps), the wrist extensors (90th wrist extensors), and the upper trapezius descendens (90th upper trapezius) for the various types of boxes (1 to 7) at each handling height (FS-G, FS-GT, FS-A). The superscript numbers indicate a statistically significant difference between the boxes ($P \leq 0.002$). FS-G: handling from a fixed surface to the ground; FS-GT: handling from a fixed surface to an adjusted surface at the height of the right great trochanter; FS-A: handling from a fixed surface to an adjusted surface at the height of the right acromion. The data are presented as percentages of maximum voluntary contraction.

			 A **(1)**	 B1 **(2)**	 B2 **(3)**	 B3 **(4)**	 C1 **(5)**	 C2 **(6)**	 C3 **(7)**
FS-G	90th biceps	R	39.3 (±20.6)	46.2 (±20.0)	48.3 (±23.1)	49.3 (±22.5)	39.9 (±23.4)	43.6 (±)	43.4 (±22.3)
		L	39.3 (±16.6)	48.5 (±19.6)	48.2 (±18.9)	51.1 (±21.3)	42.9 (±19.2)	48.1 (±)	47.1 (±18.9)
	90th wrist extensors	R	28.3 (±14.0)	36.5 (±16.3)	35.9 (±19.0)	37.0 (±18.2)	35.5 (±18.2)	38.7 (±)	38.4 (±18.8)
		L	27.6 (±12.6)$^{1/7}$	36.5 (±17.7)	36.9 (±15.9)	38.0 (±14.6)	34.3 (±15.2)	40.6 (±)	40.9 (±19.5)$^{1/7}$
	90th upper trapezius	R	35.5 (±13.7)	43.1 (±26.2)	37.6 (±16.3)	36.8 (±21.7)	34.3 (±14.0)	31.6 (±)	30.1 (±13.0)
		L	38.4 (±18.7)	40.9 (±19.3)$^{2/7}$	37.6 (±18.4)	32.6 (±16.5)	33.9 (±15.7)	31.7 (±)	29.3 (±15.5)$^{2/7}$
FS-GT	90th biceps	R	52.2 (±30.6)	62.1 (±37.6)	59.8 (±34.8)	55.8 (±30.6)	59.1 (±32.3)	55.0 (±27.9)	53.7 (±26.1)
		L	52.5 (±22.8)	61.6 (±25.9)	58.4 (±24.4)	57.5 (±25.6)	57.8 (±22.7)	55.4 (±22.5)	53.8 (±20.2)
	90th wrist extensors	R	37.8 (±23.8)$^{1/4}$	43.7 (±28.5)	50.7 (±33.0)	53.6 (±25.3)$^{1/4}$	49.3 (±31.3)	54.1 (±31.2)	53.8 (±30.3)
		L	37.7 (±18.0)	41.2 (±23.1)	45.4 (±19.7)	44.3 (±17.7)	46.2 (±25.3)	46.6 (±20.0)	50.6 (±25.5)
	90th upper trapezius	R	79.4 (±26.7)	74.2 (±28.6)	75.7 (±25.1)	74.0 (±24.7)	77.8 (±33.4)	78.0 (±34.4)	78.5 (±30.5)
		L	81.2 (±19.8)	75.9 (±21.1)	76.3 (±22.1)	75.2 (±22.5)	79.4 (±22.3)	75.7 (±22.4)	75.5 (±23.4)
FS-A	90th biceps	R	48.1 (±24.7)	57 (±28.5)	53.2 (±28.4)	52.9 (±29.6)	49.3 (±25.2)	49.6 (±25.5)	47.1 (±24.4)
		L	41.3 (±16.8)	51.9 (±19.4)	47.6 (±18.4)	48.3 (±17.0)	47.9 (±18.8)	47.5 (±17.3)	47.4 (±20.7)
	90th wrist extensors	R	22.3 (±13.4)$^{1/4}$	34.3 (±22.4)	34.4 (±20.2)	38.7 (±20.3)$^{1/4}$	32.6 (±19.1)	34 (±18.5)	38.2 (±22.2)
		L	22.9 (±12.0)	29.8 (±17.6)	33.3 (±18.2)	37.8 (±17.2)	29.9 (±13.9)	32.3 (±13.2)	35.6 (±15.4)
	90th upper trapezius	R	36.3 (±14.6)	39.4 (±21.9)	34.8 (±21.1)	32.1 (±18.0)	27.7 (±13.0)	25.5 (±11.3)	24.6 (±13.1)
		L	41.2 (±19.4)	39.9 (±22.1)	37.1 (±21.2)	34.2 (±18.2)	30.7 (±16.9)	28.2 (±13.7)	25.8 (±13.1)

Table 2. Means and standard deviations (±SD) for the right (R) and left (L) upper arm elevation (90th upper arm elevation) for the various types of boxes (1 to 7) at each handling height (FS-G; FS-GT; FS-A). The superscript numbers indicate a statistically significant difference between the boxes ($P \leq 0.002$). FS-G: handling from a fixed surface to the ground. FS-GT: handling from a fixed surface to an adjusted surface at the height of the right great trochanter. FS-A: handling from a fixed surface to an adjusted surface at the height of the right acromion. The motion data are presented in degrees (°).

			 A **(1)**	 B1 **(2)**	 B2 **(3)**	 B3 **(4)**	 C1 **(5)**	 C2 **(6)**	 C3 **(7)**
FS-G	90th upper arm elevation	R	49.7 (±8.8)$^{1/5,1/6,1/7}$	51.4 (±9.5)$^{2/5,2/6,2/7}$	48.9 (±10.3)$^{3/6,3/7}$	46.4 (±6.7)$^{4/7}$	43.4 (±8.7)$^{1/5,2/5}$	41.7 (±7.1)$^{1/6,2/6,3/6}$	41.0 (±6.0)$^{1/7,2/7,3/7,4/7}$
		L	52.6 (±14.2)$^{1/5,1/6,1/7}$	52.5 (±14.1)$^{2/6,2/7}$	49.0 (±14.4)$^{3/6,3/7}$	46.1 (±14.0)	45.8 (±14.4)$^{1/5}$	42.1 (±14.1)$^{1/6,2/6,3/6}$	42.1 (±14.0)$^{1/7,2/7,3/7}$
FS-GT	90th upper arm elevation	R	49.0 (±8.1)$^{1/4,1/5,1/6,1/7}$	47.5 (±11.9)$^{2/6,2/7}$	44.5 (±9.9)$^{3/6,3/7}$	42.7 (±8.8)$^{1/4}$	39.4 (±7.3)$^{1/5}$	37.1 (±7.9)$^{1/6,2/6,3/6}$	37.1 (±7.6)$^{1/7,2/7,3/7}$
		L	52.0 (±13.9)$^{1/5,1/6,1/7}$	50.1 (±14.1)$^{2/5,2/6,2/7}$	48.4 (±14.3)$^{3/5,3/6,3/7}$	46.2 (±14.3)$^{4/7}$	41.5 (±14.8)$^{1/5,2/5,3/5}$	41.8 (±14.7)$^{1/6,2/6,3/6}$	39.5 (±14.8)$^{1/7,2/7,3/7,4/7}$
FS-A	90th upper arm elevation	R	101.0 (±7.7)$^{1/2,1/5,1/6,1/7}$	94.8 (±6.5)$^{1/2,2/5,2/6,2/7}$	97.4 (±8.2)$^{3/5,3/6,3/7}$	97.4 (±7.7)$^{4/5,4/6,4/7}$	88.8 (±10.6)$^{1/5,2/5,3/5,4/5}$	88.9 (±9.7)$^{1/6,2/6,3/6,4/6}$	87.7 (±6.6)$^{1/7,2/7,3/7,4/7}$
		L	101.5 (±11.9)$^{1/2,1/5,1/6,1/7}$	93.2 (±11.2)$^{1/2}$	95.4 (±12.1)	96.2 (±10.9)$^{4/6,4/7}$	90.1 (±14.3)$^{1/5}$	88.6 (±13.4)$^{1/6,4/6}$	88.0 (±11.4)$^{1/7,4/7}$

biceps brachii and the wrist muscles, smaller values were associated with the commercial box.

Higher percentage values of electromyographic activity (i.e., a greater muscle workload) were recorded when the boxes were moved between FS-GT for all of the muscle groups evaluated.

The data for the muscle electrical activity of the left wrist extensors for one individual were lost. Therefore, all of the electromyographic activity variables for that muscle group in that subject were eliminated from the analysis.

Recorded arm-lifting movements

With regard to the arm-lifting range of motion, the lowest values were recorded for the C3 prototype in all of the conditions evaluated (Table 2). The statistically significant differences are shown in Table 2.

The largest ranges of arm-lifting motion (and therefore the greatest postural workload) were observed when the subjects lifted commercial box A.

Recorded wrist and elbow movements

The average values and standard deviations collected with the electrogoniometer are shown in Table 3. The 10^{th} and 90^{th} percentiles are shown because they represent, respectively, the highest levels of postural workload for wrist extension (10th percentile) and ulnar deviation and elbow flexion (90th percentile). The statistically significant differences are also shown in Table 3.

None of the prototypes produced lower workloads for all of the joints we evaluated, but there were significant differences between different prototypes in different conditions.

With regard to elbow flexion, the B3 prototype (high handle at a 30^0 angle) produced ranges of motion that were closest to the biomechanical ideal (80º to 120°) in all the conditions evaluated. With regard to wrist extension, relatively smaller ranges of motion were observed when the subjects handled the commercial box (A) and the C1 prototype (high handle with no angle), whereas greater values (and therefore greater postural workloads) were recorded when the subjects handled the C3 prototype.

The ulnar deviation in the wrist was closest to the neutral range of motion when the subjects moved the C3 prototype from FS-G and FS-GT and when the subjects moved the B1 prototype from FS-A. The ulnar deviation values displayed greater ranges for the B1 prototype in the FS-G condition and for the A prototype in the FS-G and FS-A conditions.

Evaluation of handling preferences

The average values and standard deviations of the preferences of the participants for the different handles, recorded using the acceptability scale, are shown in Table 4.

Higher average values on the acceptability scale were found for the boxes with high handles (C2, A, and C3) when the boxes were moved toward the floor or picked up from the floor. Moving the boxes to the high surface prompted the worst evaluations for all of the boxes. The low handles (B1, B2, and B3) received the best evaluations when the boxes were moved between intermediate surfaces.

Discussion

The results suggest that positive conditions for one joint can occur at the expense of another joint when the entire upper limb has to handle boxes using different grips and support surfaces.

The EGM results for the biceps brachii muscle showed that the commercial box resulted in the lowest EGM values for all of the heights we evaluated. However, the commercial box also produced the best results for the wrist extensor muscles when the box was moved between FS-G and FS-GT. Moving the B1 prototype between FS-A resulted in lower electrical activity values for the wrist extensor muscles. With respect to the descending portion of the trapezius muscle, the C3 prototype produced the best results when the box was moved between FS-G and FS-GT. The B3 prototype was the best box evaluated for movements between FS-A. Antony and Keir[27] evaluated shoulder muscle activation during isometric and prehension movements. The authors found 2% and 6% increases in the electrical activity in the biceps and trapezius muscles, respectively, when prehension movements were performed. The authors stated that changes in muscle activation patterns affect the internal load of the muscles, which plays a key role in preventing and treating musculoskeletal disorders.

With regard to arm lifting, the C3 prototype resulted in the smallest range of motion for all of the handling heights tested. A possible explanation for this result is the fact that the lower position of the handles allows the lifter to hold the load closer

Table 3. Means and standard deviations (±SD) for right (R) and left (L) elbow flexion (90th elbow flexion, +), wrist extension (10th wrist extension, –) and wrist ulnar deviation (90th wrist ulnar deviation, +) for the various types of boxes (1 to 7) at each handling height (FS-G; FS-GT; FS-A). The superscript numbers indicate statistically significant differences between the boxes ($P \leq 0.002$). FS-GT: handling from a fixed surface to an adjusted surface at the height of the right great trochanter. FS-A: handling from a fixed surface to an adjusted surface at the height of the right acromion. The motion data are presented in degrees (°).

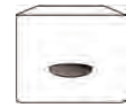
			 A **(1)**	 B1 **(2)**	 B2 **(3)**	 B3 **(4)**	 C1 **(5)**	 C2 **(6)**	 C3 **(7)**
FS-G	90th elbow flexion (+)	R	76.4 (±10.4)	74.0 (±10.7)	76.7 (±11.7)	77.8 (±10.9)$^{4/6}$	68.5 (±12.4)	69.5 (±9.9)$^{4/6}$	69.6 (±10.5)
		L	70.6 (±11.2)$^{1/5}$	68.3 (±10.8)	69.7 (±9.8)$^{3/5,3/7}$	72.1 (±10.7)$^{4/5,4/6,4/7}$	61.2 (±10.5)$^{1/5,3/5,4/5}$	63.5 (±9.7)$^{4/6}$	63.0 (±8.8)$^{3/7,4/7}$
	10th wrist extension (–)	R	–23.6 (±8.2)$^{1/7}$	–25.3 (±7.5)$^{2/7}$	–26.5 (±7.5)	–29.0 (±7.7)	–24.8 (±7.1)$^{5/7}$	–27.1 (±7.5)	–31.4 (±6.8)$^{1/7,2/7,5/7}$
		L	–23.1 (±7.5)$^{1/4,1/6,1/7}$	–26.4 (±8.6)$^{2/4,2/7}$	–28.9 (±9.7)	–32.3 (±7.6)$^{1/4,2/4}$	–27.2 (±7.0)	–29.3 (±6.5)$^{1/6}$	–32.5 (±7.0)$^{1/7,2/7}$
	90th wrist ulnar deviation (+)	R	16.2 (±8.4)$^{1/7}$	16.2 (±9.00)$^{2/7}$	15.4 (±8.5)$^{3/7}$	12.0 (±9.3)$^{4/7}$	15.6 (±8.8)$^{5/7}$	11.8 (±8.7)	6.4 (±8.4)$^{1/7,2/7,3/7,4/7,5/7}$
		L	14.6 (±9.3)$^{1/7}$	16.3 (±7.8)$^{2/7}$	15.4 (±8.3)$^{3/7}$	11.3 (±8.1)$^{4/7}$	16.0 (±7.5)$^{5/7}$	11.4 (±7.1)$^{6/7}$	4.6 (±7.4)$^{1/7,2/7,3/7,4/7,5/7,6/7}$
FS-GT	90th elbow flexion (+)	R	79.3 (±10.0)$^{1/5}$	78.1 (±10.8)	78.6 (±11.0)	82.0 (±9.1)$^{4/5,4/6,4/7}$	71.2 (±9.8)$^{1/5,4/5}$	73.1 (±9.3)$^{4/6}$	72.2 (±9.2)$^{4/7}$
		L	72.4 (±11.5)	71.6 (±10.7)	72.0 (±10.5)	74.6 (±10.9)$^{4/5}$	65.7 (±10.2)$^{4/5}$	66.8 (±10.4)	67.7 (±9.9)
	10th wrist extension (–)	R	–21.8 (±7.7)$^{1/4,1/7}$	–20.0 (±8.2)$^{2/4,2/7}$	–22.2 (±8.1)$^{3/7}$	–27.2 (±7.8)$^{1/4,2/4,4/5}$	–20.2 (±9.4)$^{4/5,5/7}$	–25.3 (±6.9)	–30.3 (±8.6)$^{1/7,2/7,3/7,5/7}$
		L	–19.2 (±7.0)$^{1/4,1/6,1/7}$	–21.3 (±9.5)$^{2/4,2/7}$	–22.2 (±7.4)$^{3/7}$	–25.8 (±7.2)$^{1/4,2/4,4/5}$	–19.2 (±8.9)$^{4/5,5/7}$	–23.3 (±7.1)$^{1/6,6/7}$	–28.9 (±7.6)$^{1/7,2/7,3/7,5/7,6/7}$
	90th wrist ulnar deviation (+)	R	15.9 (±8.8)$^{1/7}$	14.0 (±12.9)$^{2/7}$	14.9 (±12.3)$^{3/7}$	12.5 (±8.6)$^{4/7}$	13.5 (±11.2)$^{5/7}$	11.8 (±10.3)$^{6/7}$	4.7 (±9.0)$^{1/7,2/7,3/7,4/7,5/7,6/7}$
		L	16.2 (±9.2)$^{1/7}$	13.0 (±12.1)$^{2/7}$	13.1 (±10.6)$^{3/7}$	10.8 (±11.2)$^{4/7}$	12.2 (±12.9)$^{5/7}$	10.6 (±8.3)$^{6/7}$	4.3 (±6.7)$^{1/7,2/7,3/7,4/7,5/7,6/7}$
FS–A	90th elbow flexion (+)	R	80.1 (±12.3)	79.0 (±12.4)	79.3 (±11.0)	80.9 (±10.9)	72.6 (±11.5)	75.1 (±11.5)	74.7 (±10.7)
		L	73.8 (±11.4)	72.3 (±11.0)	73.5 (±10.5)	74.9 (±10.6)$^{4/5}$	66.0 (±10.5)$^{4/5}$	67.6 (±10.7)	68.1 (±10.2)
	10th wrist extension (–)	R	–22.5 (±8.0)$^{1/2,1/4,1/7}$	–31.0 (±11.3)$^{1/2}$	–30.0 (±12.2)	–30.6 (±10.1)$^{1/4}$	–27.0 (±9.3)	–27.5 (±9.4)	–30.6 (±7.9)$^{1/7}$
		L	–21.1 (±6.8)$^{1/2,1/3,1/4,1/7}$	–28.6 (±11.9)$^{1/2}$	–29.4 (±9.8)$^{1/3}$	–30.6 (±7.8)$^{1/4}$	–25.6 (±10.4)	–25.6 (±7.5)	–29.5 (±6.1)$^{1/7}$
	90th wrist ulnar deviation (+)	R	17.6 (±9.2)	12.0 (±10.7)	13.8 (±10.2)	13.9 (±9.5)	15.8 (±9.8)	17.6 (±8.7)	15.5 (±8.3)
		L	18.1 (±8.4)	10.5 (±13.9)	13.4 (±13.4)	11.4 (±13.4)	16.2 (±9.9)	16.9 (±8.8)	14.2 (±11.4)

Table 4. Means and standard deviations (±SD) of the acceptability scale for the various types of boxes (1 to 7) at each handling height (FS-G; FS-GT and FS-A). The superscript numbers indicate statistically significant differences between the boxes ($P \leq 0.05$). FS-G: handling from a fixed surface to the ground. FS-GT: handling from a fixed surface to an adjusted surface at the height of the right great trochanter. FS-A: handling from a fixed surface to an adjusted surface at the height of the right acromion.

	Subjective Acceptability Scale		
	FS-G	**FS-GT**	**FS-A**
 A (1)	6.0 (±2.0)	5.5 (±1.8)	4.0 (±2.2)$^{1/4}$
 B1 (2)	5.4 (±2.0)	6.1 (±2.2)	4.5 (±2.0)
 B2 (3)	5.5 (±2.0)	6.5 (±2.1)	5.4 (±2.1)
 B3 (4)	5.3 (±2.2)	6.4 (±2.3)	5.8 (±2.4)$^{1/4,4/5}$
 C1 (5)	5.2 (±1.9)	5.2 (±2.0)	4.1 (±2.0)$^{4/5}$
 C2 (6)	6.1 (±1.9)	5.7 (±2.3)	4.6 (±2.1)
 C3 (7)	5.9 (±2.1)	5.8 (±2.6)	5.0 (±2.1)

to the body, thereby reducing the distance from the arms to the support surfaces.

The results for the arm-lifting movements corroborate the results for the electrical activity in the trapezius muscle, in the sense that muscle activity was lower when there was a smaller distance for the arms. Nielsen et al.[28], in evaluating the electrical activity of the trapezius and the erector spinae muscles, found that there is a workload change in the spinal region for the shoulders when objects are moved from very low surfaces (the floor) to surfaces close to shoulder level. The authors recommended that boxes be handled between heights 72.5 to 126.8 cm above the ground. The greatest EMG activity for the trapezius when handling box C occurred when the joints assumed extreme postures, hindering torque generation (the ratio of muscle length/tension). In these extreme positions, additional motor units can be recruited and/or the firing frequency of already activated motor units can increase[29], which explains the increase in the EMG activity of the muscles evaluated.

During the electrogoniometric recording of elbow flexion, the B3 prototype produced the ranges of motion with the greatest biomechanical advantage (80° to 120°)[30] for all of the handling heights we evaluated. This result was expected because the higher handle position favors elbow flexion.

Regarding wrist extension, handling the commercial box (A) produced ranges closer to the neutral position when the box was moved from FS-G and FS-A. For movements between FS-GT, the C1 prototype produced the ranges of motion that were closest to the neutral position. Deviations of the wrist from the neutral position cause increased pressure on the carpal tunnel and decreased the power of the intrinsic wrist muscles in the lever arm[31]. Forceful movements and extreme ranges of motion of the wrist should be avoided because they are associated with increased workload and musculoskeletal disorders[32].

Handling the C3 prototype produced ranges of motion closest to the neutral position when the box was moved from FS-G and FS-GT. For movements between FS-A, the B1 prototype produced the best results in terms of deviation movements. These results are in agreement with those obtained in previous studies[11,12] that have recommended handles angled at 30º or 45° from the horizontal plane.

When direct quantitative data are used to evaluate movement, it is important to consider the extent to which the significant differences observed between the conditions (boxes) affect the range of motion from the clinical or preventative point of view. In this study, 10% of the average range of motion for each joint (maximum range – minimum range) was considered a relevant measure for evaluating the differences between the boxes we evaluated[33]. Given this standard, the statistically significant differences we found between the boxes with regard to arm lifting, elbow flexion, wrist extension, and ulnar deviation are clinically relevant. The following average ranges of motion were recorded for each joint: 50° for arm lifting (5° difference between the conditions), 56° for elbows (6° difference between the conditions), 38° for wrist extension (4° difference between the conditions), and 31° for ulnar deviation of the wrist (3° difference between the conditions).

The subjects' preferences for different handles varied depending on the surface height. The prototypes with high handles tended to obtain higher scores for handling between intermediate surfaces, and high handles also tended to receive better evaluations for handling tasks involving the ground. The acceptability scores are in agreement with the elbow flexion results: for both variables, the best prototype was the B3 prototype.

Interestingly, smaller ranges of elbow flexion (greater workload) occurred in situations with greater ranges of ulnar deviation (greater workload) for the C1 prototype, apparently because synergistic strategies were used to handle this prototype at different heights. Similar to the C1 prototype, the commercial box (A) also has a handle in a high and straight position, but the same result was not observed for A. This result may have occurred because the handle on the commercial box is held with a closed hand, and the hole in the box may have produced greater synergy between the agonist and the antagonist wrist muscles.

Another synergistic strategy seems to have occurred when the subjects handled the C3 prototype (high and straight handle): the better positioning of the shoulder promoted lower levels of muscle activity in the trapezius and more neutral ulnar deviation positions, but some of the wrist extension motion was lost.

In general, the B3 and C3 boxes had a greater ratio of positive aspects to negative aspects with respect to muscle electrical activity, postures adopted, and acceptability for the subjects performing the activity. The B3 prototype would be most suitable for handling tasks below the waist, and the C3 prototype would be best for handling tasks above the waist. In both prototypes, the handles are tilted 30°. Training programs for users focusing on how to perform the necessary adjustments to the box depending on the surface heights are highly recommended.

Future studies that include workers who are experienced in handling tasks in real environments are necessary to validate these results and to make continued improvements in new prototypes. Including inexperienced people in this study produced the required homogeneity of the sample, but this sampling strategy could limit the external validity of the results for workers. Future studies could also evaluate other joints associated with the upper limbs to evaluate the workload on the musculoskeletal system more comprehensively. One strength of this study was that direct measurements were collected simultaneously, which should be required in future studies. It would be equally interesting to analyze the electrical signals of the antagonist muscles when the upper limbs are moving in future studies to verify whether the joints are stable during handling. Furthermore, prospective studies are needed to verify whether adjusting the handle designs on boxes reduces musculoskeletal symptoms among real users.

Acknowledgements

This study received financial support from the National Council on Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq Proc. No. 142408/2009-3 and Proc. 301772/2010-0).

References

1. Lin CJ, Wang SJ, Chen HJ. A field evaluation method for assessing whole body biomechanical joint stress in manual lifting tasks. Ind Health. 2006;44(4):604-12. PMid:17085922.
2. Ciriello VM. The effects of container size, frequency and extended horizontal reach on maximum acceptable weights of lifting for female industrial workers. Appl Ergon. 2007;38(1):1-5. PMid:16616883. http://dx.doi.org/10.1016/j.apergo.2006.02.001
3. Splittstoesser RE, Yang G, Knapik GG, Trippany DR, Hoyle JA, Lahoti P, et al. Spinal loading during manual materials handling in a kneeling posture. J Electromyogr Kinesiol. 2007;17(1):25-34. PMid:16517181. http://dx.doi.org/10.1016/j.jelekin.2005.12.003
4. Padula RS, Souza VC, Gil Coury HJC. Tipos de preensão e movimentos do punho durante atividade de manuseio de carga. Rev Bras Fisioter. 2006;10(1):29-34. http://dx.doi.org/10.1590/S1413-35552006000100004
5. Dempsey PG, Hashemi L. Analysis of workers' compensation claims associated with manual material handling. Ergonomics. 1999;42(1):183-95. PMid:9973880.
6. Lortie M, Baril-Gingras G. Box handling in the loading and unloading of vans. Int J Occup Saf Ergon. 1998;4(1):3-18. PMid:10602604.

7. Jung HS, Jung HS. A survey of the optimal handle position for boxes with different sizes and manual handling positions. Appl Ergon. 2010;41(1):115-22. PMid:19589498. http://dx.doi.org/10.1016/j.apergo.2009.06.004

8. Drury CG. Handles for manual materials handling. Appl Ergon. 1980;11(1):35-42. PMid:15676373. http://dx.doi.org/10.1016/0003-6870(80)90120-9

9. Ciriello VM, Snook SH, Hughes GH. Further studies of psychophysically determined maximum acceptable weights and forces. Hum Factors. 1993;35(1):175-86. PMid:8509102. http://dx.doi.org/10.1177/001872089303500110

10. Drury CG, Deeb JM, Hartman B, Woolley S, Drury CE, Gallagher S. Symmetric and asymmetric manual materials handling Part 1: physiology and psychophysics. Ergonomics. 1989;32(5):467-89. PMid:2767042, DOI: 10.1080/00140138908966118

11. Chung H-C, Wang M-J. The effects of container design and stair climbing on maximal acceptable lift weight, wrist posture, psychophysical, and physiological responses in wafer-handling tasks. Appl Ergon. 2001;32(6):593-8. PMid:11703045. http://dx.doi.org/10.1016/S0003-6870(01)00039-4

12. Wang M-J, Chung H-C, Chen H-C. The effect of handle angle on MAWL wrist posture, RPE, and heart rate. Hum Factors. 2000;42(4):553-565. PMid:11324850. http://dx.doi.org/10.1518/001872000779698079

13. Åkesson I, Balogh I, Hansson G-Å. Physical workload in neck, shoulders and wrists/hands in dental hygienists during a work-day. Appl Ergon. 2012;43(4):803-11. PMid:22208356. http://dx.doi.org/10.1016/j.apergo.2011.12.001

14. Instituto Brasileiro de Geografia e Estatística - IBGE. Séries estatísticas & históricas. 2009. Brazil. [cited 2012 Mar 07]. Available from: http://seriesestatisticas,ibge,gov,br/series,aspx?vcodigo=PD292&sv=19&t=grupos-deidade.

15. Oliveira AB, Silva LC, Coury HJ. How do low/high height and weight variation affect upper limb movements during manual material handling of industrial boxes? Rev Bras Fisioter. 2011;15(6):494-502. PMid:21877063. http://dx.doi.org/10.1590/S1413-35552011005000029

16. Paschoarelli LC, Oliveira AB, Gil Coury HJC. Assessment of the ergonomic design of diagnostic ultrasound transducers through wrist movements and subjective evaluation. Int J Ind Ergon. 2008;38(11-12):999-1006. http://dx.doi.org/10.1016/j.ergon.2008.01.013

17. Silva LC, Oliveira AB, Silva DC, Paschoarelli LC, Coury HJCG. Evaluation of reusable cardboard box designs: Biomechanical and perceptual aspects. Int J Ind Ergon. 2013;43:154-160. http://dx.doi.org/10.1016/j.ergon.2012.12.001/

18. Stål M, Hansson GÅ, Ulrich M. Upper extremity muscular load during machine milking. Int J Ind Ergon. 2000;26(1):9-17. http://dx.doi.org/10.1016/S0169-8141(99)00059-1

19. Freriks B, Hermens HJ. SENIAM 9: European recommendations for surface electromyography. Roessingh Research and Development; 1999. [CD-room].

20. Mathiassen SE, Winkel J, Hägg GM. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies – A review. J Electromyogr Kinesiol. 1995;5(4):197-261. PMid:20719652. http://dx.doi.org/10.1016/1050-6411(94)00014-X

21. Akesson I, Hansson G-A, Balogh I, Moritz U, Skerfving S. Quantifying work load in neck, shoulders and wrists in female dentists. Int Arch Occup Environ Health. 1997;69(6):461-74. PMid:9215934.

22. Hansson GA, Asterland P, Holmer N-G, Skerfving S. Validity and reliability of triaxial accelerometers for inclinometry in posture analysis. Med Biol Eng Comput. 2001;39(4):405-13. PMid:11523728. http://dx.doi.org/10.1007/BF02345361

23. Hansson GA, Arvidsson I, Ohlsson K, Nordander C, Mathiassen SE, Skerfving S, et al. Precision of measurements of physical workload during standardised manual handling. Part II: Inclinometry of head, upper back, neck and upper arms. J Electromyogr Kinesiol. 2006;16(2):125-36. PMid:16102977. http://dx.doi.org/10.1016/j.jelekin.2005.06.009

24. Biometrics. Goniometer and torsiometer operating manual. Gwent; 2007.

25. Søgaard K, Laursen B, Jensen Br, Sjøgaard G. Dynamic loads on the upper extremities during two different floor cleaning methods. Clin Biomech. 2001;16(10):866-79. PMid:11733124.

26. Chen H-C, Chang C-M, Liu Y-P, Chen C-Y. Ergonomic risk factors for the Wrists of hairdressers. Appl Ergon. 2010;41(1):98-105. PMid:19497556. http://dx.doi.org/10.1016/j.apergo.2009.05.001

27. Antony NT, Keir PJ. Effects of posture, movement and hand load on shoulder muscle activity. J Electromyogr Kinesiol. 2010;20(2):191-8. PMid:19473855.

28. Nielsen PK, Andersen L, Jørgensen K. The muscular load on the lower back and shoulders due to lifting at different lifting heights and frequencies. Appl Ergon. 1998;29(6):445-50. PMid:9796790. http://dx.doi.org/10.1016/S0003-6870(98)00005-2

29. Merletti R, Parker PA. Electromyography: physiology engineering and noninvasive applications. New Jersey: John Wiley & Sons Inc. Hoboken; 2004.

30. Murray WM, Delp SL, Buchanan TS. Variation of muscle moment arms with elbow and forearm position. J Biomech. 1995;28(5):513-25. PMid:7775488.

31. Wells R, Keir P. Work and Activity-related Musculoskeletal Disorders of the Upper Extremity In: Kumar S, editor. Biomechanics in Ergonomics. London: Ed by S Kumar Taylor & Francis; 1999.

32. Sande LP, Coury HJCG, Oishi J, Kumar S. Effect of musculoskeletal disorders on prehension strength. Appl Ergon. 2001;32(6):609-16. PMid:11703047.

33. American Medical Association - AMA. Guides to evaluation of permanent impairment. Chicago: AMA; 2005.

Correspondence

Helenice Jane Cote Gil Coury
Universidade Federal de São Carlos
Departamento de Fisioterapia
Rod. Washington Luiz, Km 235
CEP 13565-905, São Carlos, SP, Brasil
e-mail: helenice@ufscar.br