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Effect of Mailbag Design on Musculoskeletal Fatigue and Metabolic Load

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The need for an alternative mailbag to the conventional U.S. postal mailbag, which hangs at the side over one shoulder, was investigated. Based on the results of a pilot study, two types of alternative mailbags, both including waist support and one that splits the load into two parts, are recommended. The metabolic energy requirement and lateral trunk muscle fatigue resulting from the use of the alternative mailbags were compared with those resulting from the conventional U.S. postal mailbag. The alternative mailbags resulted in no significant change in metabolic load. Both alternative mailbags resulted in significantly less lateral trunk muscle fatigue. It is proposed that this reduction in fatigue would result in reduced musculoskeletal stress and reduced potential for back injury.

INTRODUCTION

Injury Statistics

Letter carriers compose an occupational group that is at risk for musculoskeletal disorders. Wells, Zipp, Schuette, and McEleney (1983) noted that between 1975 and 1980, 64% of letter carrier disability retirements in the St. Louis area were caused by musculoskeletal problems and that an additional 21% of postal workers suffered from musculoskeletal problems that were not the major cause of their disability. They proposed that the load-carrying activity was the cause of the high rate of musculoskeletal disorders.

Page (1985), however, found that the direct compressive load on the spine was minimal but that muscular stress on the trunk muscles opposite or contralateral to the load was significant when carrying 15.9 kg. The standard mailbag, or U.S. Postal Service mail satchel, is a fabric bag carried by looping a strap over the ipsilateral (same side as the bag) shoulder or contralateral (opposite side) shoulder, which results in stress on the contralateral trunk muscles. Page concluded that a source of low back disorders in letter carriers was fatigue of the lateral trunk muscles, in combination with shear forces from an asymmetrical load on the spine.

Page also demonstrated that wearing a pelvic waist belt to support the load reduced the required contractile force of the contralateral trunk muscles. Cook and Neumann (1984) found that the muscle activity of the contralateral muscles is reduced with this type of support. Imrie and Crosbie (1982), Holewijn and Lotens (1992), and Vernon and Laufer (1982) found that supporting the load at the waist resulted in less discomfort and was preferred by most subjects.

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Oja, Louhevaara, and Korhonen (1977) found that the mean relative aerobic strain over the entire delivery time of postal workers was 55% of the maximal oxygen uptake and increased after age 50. Ilmarinen, Louhevaara, and Oja (1984) found that the mean relative aerobic strain over the entire delivery time ranged from 30.6% to 54.3% of maximal oxygen uptake. They suggest that the metabolic load might lead to excessive physiological strain on the workers.

Study Background

The United Postal Workers Union and the Salt Lake City Post Office contracted with personnel at the Mechanical Engineering Department at the University of Utah to design and test a mailbag that would present less biomechanical and physiological stress to the user. Although the research noted earlier suggests subjective acceptance of a bag supported at the waist, empirical data were lacking.

The study consisted of three parts. An initial pilot survey was performed to determine the normal use of the mailbag, establish general performance parameters, and obtain subjective opinions of alternative designs from postal personnel. Based on the results of the pilot survey, the alternative mailbags were modified slightly and two laboratory studies were performed to measure the effect of the alternative mailbag designs on metabolic load and on fatigue in the lateral trunk flexor muscles.

EXPERIMENT 1: PILOT SURVEY

Through discussions with post office managers in the Salt Lake City (Sugarhouse) Post Office it was determined that U.S. postal mailbags must meet the following performance criteria:

1. Hold a minimum of 35 lb or 15.9 kg (United States Postal Service, 1985).
2. Be movable to the front to provide protection against animal attack.
3. Be movable to the rear to allow the user to squeeze through tight spaces.
4. Be easy to put on and remove.

A design placing the bag in front of the user, as recommended by Ashton (1985), was determined to be unacceptable by post office personnel because it would obstruct vision. A design that placed the bag in a backpack orientation was unacceptable because it would limit easy access to the load.

The two alternative mailbags we developed were designed to distribute the mail load more symmetrically than a standard bag. One model included a side bag supported by a waist belt to reduce the load on the shoulders. The second alternative design, a double-bag design, consisted of two side bags supported by a waist belt. The side bag was attached to the belt by Velcro to facilitate movement to the front or rear of the user. The double bags were hung from the belt with a large hook through a loop. The three mailbag configurations are shown on Figure 1.

The side bag with waist belt and the double bag were tested by three mail carriers (two males and one female) in the Salt Lake City area for convenience and operational feasibility. Based on their comments, the bags were modified to include additional Velcro to stabilize the bags, a hook for dog repellant, less slippery shoulder straps, increased depth, and reinforced ends. An informal survey of these three users also indicated a subjective decrease in general soreness and fatigue after using both of the alternative mailbags, which agrees with the studies cited earlier.

EXPERIMENT 2: METABOLIC FATIGUE

Subjects

Nine healthy male subjects between the ages of 18 and 39 were recruited from the student population at the University of Utah. Three subjects were recruited for each of

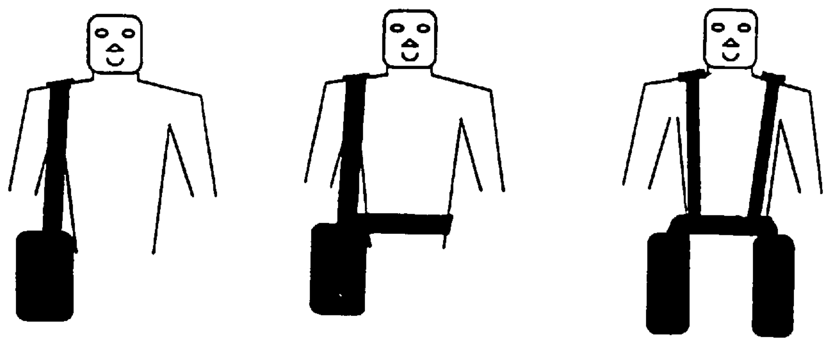

Figure 1. *Mailbag types.*

three different anthropometric categories: short (under 165 cm), average (165 cm–175.3 cm), and tall (over 175.3 cm). Weight was not controlled but was proportional to height. Subject information is presented in Table 1. Subjects were screened for history of low back pain. The study was approved by the University of Utah Institutional Review Board, and all subjects read and signed an approved informed consent form.

Apparatus and Procedure

Subjects were required to wear a mouthpiece through which expired air could be exhausted to the ambient air or collected in a previously evacuated Douglas bag. A nose clip assured that all air was directed to the air bag during expired air collection. Each subject was allowed to wear the mouthpiece and carry each of the bags with a 15.9-kg load for several minutes to become familiar with the task prior to initiation of the test.

TABLE 1

Subject Information for the Metabolic Experiment

Subject	*Height Category*	*Age (years)*	*Height (cm)*	*Weight (kg)*
1	Short	22	164	51
2	Short	30	161	70
3	Short	24	163	74
4	Medium	29	174	78
5	Medium	27	180	68
6	Medium	21	173	60
7	Tall	29	189	96
8	Tall	26	191	89
9	Tall	26	187	95
Mean		26	175.8	75.7
S.D.		3.2	11.6	15.5

The order of presentation of the mailbags was randomized, and each subject carried each mailbag twice. Each subject was instructed to walk at a comfortable pace back and forth for approximately 50 m along a smooth, level floor. The comfortable pace was subjectively determined by the subject as a pace at which he felt he could walk for several hours. It should be noted, however, that the pace was relatively brisk and was probably somewhat faster than the pace of which a carrier would walk in an entire day.

The Douglas bag was carried by one of the researchers, who walked slightly behind the subject at the same pace. At each end of the route the subject was required to walk up, turn around, and walk down a set of five steps. After the subject had reached a steady state metabolic rate (approximately 10 min), his expired air was collected for 2 min in the Douglas bags as he continued to perform the carrying task. A minimum of 5 min rest was provided between trials.

The volume of expired air, (V_E[ATPS]), was corrected to Standard Temperature and Pressure (V_E[STPD]), as noted below:

$$(V_E[\mathrm{STPD}]) = (V_E[\mathrm{ATPS}]) \times \frac{(P_B - \mathrm{WVP})}{(760\ \mathrm{mm\ Hg})} \times \frac{(273°\mathrm{K})}{(273°\mathrm{K} + T_C)}, \quad (1)$$

where P_B is ambient barometric pressure, WVP is the water vapor pressure, and T_C is the air temperature. The oxygen content of the expired air was measured with an AMTEK Model TM-1B Oxygen Analyzer (1 O_2/(min)). The oxygen consumption was then normalized to correct for differences in subject weight and walking speed. The resulting value indicated the energy requirements for each of the mailbags in terms of liters of oxygen consumed per kilogram body weight per meter walked during the collection period, 1 O_2/(kg − m). It was assumed that this is a comparative measure of the whole body of metabolic fatigue that would result from use of the different mailbags.

Results and Discussion

The average oxygen consumption for the two trials for the three mailbags for each subject is shown in Table 2. The oxygen consumption for each of the alternative mailbags as a percentage of the oxygen consumption for the conventional mailbag for each subject is shown in Table 3.

There was a general tendency for the metabolic rate to increase for the two alternative bag designs, but the effect of mailbag design on metabolic rate was not statistically significant. In addition, the smaller subjects complained that the double bags contacted their legs and felt awkward.

EXPERIMENT 3: LATERAL TRUNK FLEXOR MUSCLE FATIGUE

Subjects

Twelve healthy, right-handed male subjects were recruited from the student population at the University of Utah. They were between the ages of 18 and 39 years, 173–198 cm in height, and 61.2–95.7 kg in weight. Subject information is presented in Table 4.

In the previous metabolic study, males below 162.6 cm height complained of subjective discomfort and fatigue carrying the double bag, so only males above this height were used in this part of the study. This was done

TABLE 2

Metabolic Energy Expenditure for Different Mailbag Types [1 O_2/(min)]

	Conventional Bag	*Single Bag with Waist Belt*	*Double Bag*
1	1.28	1.36	1.35
2	1.26	1.22	1.34
3	1.65	1.63	1.55
Short sub. avg. (S.D.)	1.40 (0.19)	1.41 (0.19)	1.41 (0.10)
4	1.71	1.75	1.77
5	1.38	1.38	1.47
6	1.44	1.42	1.49
Medium sub. avg. (S.D.)	1.51 (0.13)	1.51 (0.11)	1.58 (0.12)
7	1.78	1.88	1.75
8	1.83	1.86	1.85
9	1.97	1.97	2.07
Tall sub. avg. (S.D.)	1.86 (0.08)	1.90 (0.07)	1.89 (0.16)

TABLE 3

Metabolic Energy Expenditure for Different Mailbag Types [1 O_2/(kg-m)] Expressed as a Percentage of Oxygen Consumption with the Conventional Mailbag

	Single Bag with Waist Belt	*Double Bag*
1	1.01	1.09
2	0.98	1.07
3	0.94	0.90
Short sub. avg. (S.D.)	0.98 (0.026)	1.02 (0.085)
4	1.08	1.02
5	1.02	1.06
6	1.00	1.03
Medium sub. avg. (S.D.)	1.03 (0.031)	1.04 (0.033)
7	1.06	1.00
8	1.03	1.04
9	1.01	1.06
Tall sub. avg. (S.D.)	1.03 (0.020)	1.03 (0.050)

Note. Except for the averages, each entry represents the average of two trials.

in order to isolate the effect of general trunk muscle fatigue and to reduce the effect of local muscle strain or contact trauma on the fatigue test. Subjects completed a medical history questionnaire to screen for history of low back pain. The study was approved by the University of Utah Institutional Review Board, and all subjects read and signed an approved informed consent form.

TABLE 4

Subject Information for the Lateral Flexion Fatigue Experiment

Subject	*Age (years)*	*Height (cm)*	*Weight (kg)*
1	29	188.9	95.7
2	21	172.7	61.2
3	36	175.3	87.9
4	27	180.3	69.4
5	26	190.5	87.5
6	24	174.6	76.6
7	29	181.0	82.1
8	19	180.3	71.2
9	24	198.1	84.8
10	21	178.4	75.7
11	19	183.5	89.3
12	36	185.4	89.3
Mean	25.9	182.4	80.9
S.D.	5.8	7.3	10.1

Method

The lateral trunk flexion fatigue (LTFF) test followed guidelines established for the Sorensen's fatigue test (Biering-Sorensen, 1983). The subjects were positioned on their right side on a Saba Angle Bench. Each placed his right arm across his chest and left arm along the left side of his body. Braces anchored by C-clamps prevented hip rotation, and the subject's superior iliac crest rested on the edge of the bench. This task consisted of measuring how many seconds the subject was able to keep the unsupported upper part of the body horizontal. Fatigue was operationally defined as the time required for the subject to drop 5 cm below a horizontal marker after the investigator gave the subject one opportunity to correct horizontal alignment. Consistent performance information and verbal encouragement to perform at maximal effort were provided to all subjects to minimize differences in motivation.

Horizontal alignment was measured by correlating a marker on the C7 spinous process to an adjustable external marker on a stationary post. Subjects were given similar instructions for every test. The time to fatigue (length of time that the subject can maintain the horizontal position) is a measure of fatigue in the lateral trunk flexors.

Preliminary studies. A preliminary study established the test-retest reliability data for the LTFF test. At the same time of day, over a three-day period, one investigator performed the test on six subjects. The reliability coefficient, calculated using Cronbach's alpha, for all three days was 0.76. Removing the first day's results from the analysis, as well as the results from a subject who experienced delayed onset muscle soreness, improved the reliability to 0.96. These data demonstrated a learning effect with a plateau of times occurring for the final two trials.

A second preliminary study was performed to determine if the LTFF would be sensitive enough to measure fatigue experienced while carrying a side bag. The LTFF test was administered before and after walking a simulated mail route. Subjects 1 and 2 walked for 30 min; Subject 3 walked for 45 min; and Subject 4 walked for 70 min. Each subject carried 13.6 kg in a side bag without a waist belt. The subjects underwent three trials with 30 min rest between trials to minimize the effect of latent fatigue. The results showed that 30 min provided sufficient time for recovery from muscle fatigue.

The difference between pre- and postfatigue scores increased as walking time increased, thereby demonstrating a dose-response relationship. Also, there was no overlap of pre- and posttest scores, demonstrating sensitivity of the test to fatigue. The test possessed a discriminatory function to identify individuals unable to maintain a required work output.

A third preliminary study analyzed the prime muscle movers for lateral trunk flexion. Electromyography (EMG) analysis confirmed that the contralateral external obliques and the iliocostalis were active both while walking with a standard mailbag and during the LTFF test. Congruent validity was demonstrated when the EMG data revealed that the prime muscle movers responsible for carrying a standard mailbag were active during the LTFF test (Bogduk and Twomey, 1987).

Lateral trunk flexion fatigue test. During the study the subjects carried 15.9 kg in the conventional U.S. Postal Service mailbag and the two alternative mailbags during a 1-h simulated mail delivery route. For the conventional bag and the side bag with waist belt, the load was carried on the right side of the body with the strap over the right shoulder. The order of mailbags carried by the subjects was randomized. Subjects received a 30-min rest between trials to minimize the effect of latent fatigue. Time to fatigue of the left lateral trunk muscles was measured before and after each circuit.

The mail delivery route was conducted indoors with obstacles to simulate a letter carrier's job as closely as possible. The course, 574 m in length, was circular with one set of four 10-cm steps, one set of six 15-cm steps, and three push-open doors. For each trial the subjects walked a total of 3.4 km at 100 paces/min. Subjects were paced using a metronome, ensuring the same absolute workload between subjects. Stride length was not controlled in order to facilitate a natural walking motion.

The total testing was accomplished over three days. The fatigue test was performed on the first day to familiarize the subject with the test protocol. To account for the learning effect found in the reliability study, the subjects performed the fatigue test a second time on Day 2. Three trials for the three different mailbags were performed on the third day. For each trial the time to fatigue of the lateral trunk flexors was recorded before and after the 1-h performance of the simulated mail delivery route. A 30-min rest period was allowed between trials and a 1-min rest was allowed between the fatigue tests and the simulated mail carrying.

Results and Discussion

A one-way ANOVA was used to test the data for significance. A difference score was computed by subtracting the posttest score from the pretest fatigue score. The pretest data are used to adjust the posttest means to account for initial differences between treatment groups and to increase the power of the analysis by reducing within-groups variability (Huck and McLean, 1975). Tukey's post hoc comparison determined which groups significantly differed.

The mean of the pretest scores significantly decreased from 108 s to 91 s and then to 84 s over the three trials. This effect is shown in Figure 2.

The difference between the pretest and posttest fatigue times was 7.07 s for the double bag, 9.23 s for the conventional bag with waist belt, and 28.18 s for the conventional bag. This is shown in Figure 3.

In spite of the accumulation of fatigue, a one-way ANOVA of gain scores indicated a

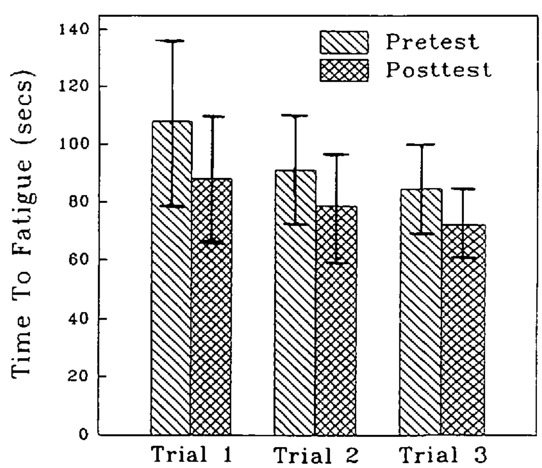

Figure 2. *Average and standard deviation of pretest and posttest time to fatigue scores comparing three trials.*

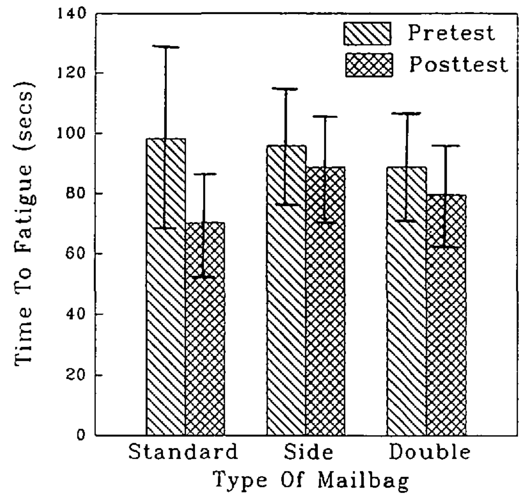

Figure 3. *Average and standard deviation of pretest and posttest time to fatigue scores comparing three mailbags.*

significant difference between treatments. A difference score was computed for three trials by subtracting each subject's posttest score from the pretest score. The difference scores were examined for normality and homogeneity of variance. The data contained no outliers and demonstrated a normal curve. Mauchly Sphericity test, a multivariate analysis, was not significant ($p < 0.80275$), demonstrating equal variances and covariances between groups. Therefore, a univariate analysis was used to assess the differences between groups (Huck and McLean, 1975). This analysis indicated that there was a significant difference in time to fatigue for the three different mailbags, $F(2,22) = 10.16$, $p < 0.001$. According to Tukey's post hoc comparison, a mean difference in time to fatigue greater than or equal to 13 s indicates significantly different responses to treatment.

There was a significant difference in fatigue scores between the standard mailbag trial compared with the trials using the double bag and the single bag with waist belt. There was no significant difference in fatigue scores between the double bag trial compared with the single bag with waist belt trial. Further calculations indicated that 30.4% of the variation in fatigue could be explained by the difference in mailbag type.

CONCLUSIONS AND RECOMMENDATIONS

This study investigated three different mailbags and the resultant effect on whole body and trunk muscle fatigue. There was no systematic difference in metabolic energy required between the mailbags. There was a significant difference in lateral trunk muscle fatigue between the conventional mailbag trial compared with the single bag with waist belt and double bag. There was no significant difference in fatigue scores between the double bag trial compared with the single bag with waist belt trial. The results suggest that the waist belt is as effective in reducing lateral trunk muscle fatigue as positioning double bags on either side of the pelvis.

The use of the double bag or side bag with waist belt should be investigated further as a potential replacement or supplement to the conventional postal mailbag.

This study needs to be repeated and should include male and female letter carriers in the small, medium, and tall categories for height and weight. The letter carriers should walk an actual mail route with uneven terrain for approximately 4 or 5 h to increase the effect size and establish whether a significant difference exists between the double bag and side bag with waist belt. A control group of walkers only (no mailbag load) is needed to discern the amount of fatigue resulting from simply walking.

Given the observation that small-stature males experienced some subjective discomfort when carrying the double bag, the best mailbag for a particular letter carrier may be dependent on anthropometric characteristics.

The subjective complaints of shoulder pain and discomfort from the side bag with waist belt and the free-swinging nature of the double bags suggest that continued redesign is needed. A new suspension system is needed for the double bags to prevent subjective discomfort from counter trunk rotation and to prevent the bags from rubbing against the subjects' thighs. The shoulder strap on the standard bag and the side bag with a waist belt should be redesigned using soft rubber that conforms to the shoulder to prevent the strap from slipping off.

Future research must be directed toward a determination if there is a significant decrease in low back injuries and worker's compensation costs when the double bag or single bag with waist belt is used. If compensation costs or number of injuries are reduced, one may infer that a primary cause of the low back injuries is trunk musculature fatigue, which may be reduced through appropriate mailbag design.

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