NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #2002-0239-2922
United States Postal Service
Norman, Oklahoma

January 2004

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Daniel J. Habes and Randy L. Tubbs, HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS) and E. Lee Husting, Analysis and Field Evaluations Branch (AFEB), Division of Safety Research. Desktop publishing was performed by Robin Smith. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of a Human Transporter to Deliver Mail

NIOSH was asked by the National Association of Letter Carriers to determine if using a human transporter to deliver mail would present health risks to workers who deliver mail.

What NIOSH Did

- We measured how much the human transporter jolts as it is driven on sidewalks, roads, driveways, and lawns.
- We measured the handlebars, the grips, and the mail bins to see if the human transporter could be used by most mail carriers.
- We videotaped workers delivering mail to see if using the human transporter changed the amount of reaching needed to deliver mail.
- We talked to mail carriers to see how they liked the human transporter.
- We looked at the procedures the post office uses to record injuries to see if new ones were needed to report accidents that occur using the human transporter.

What NIOSH Found

- Driving the human transporter over bumps on lawns, streets, driveways, and sidewalks causes a lot of jolts, but there is no easy way to determine if this is bad for mail carriers.
- The human transporter can be adjusted to fit the size of most mail carriers.
- Delivering mail with the human transporter causes less reaching in some situations and more reaching in other situations. Because the mail carriers have to get off the human transporter so often to deliver mail to a box, the motions needed are about the same no matter how it is done.
- Workers liked not having to walk or carry a mail bag, but weren't sure if using the human transporter was safer or faster than walking. Some wondered what it would be like to use the human transporter all year round.
- The post office probably doesn't need any new procedures or forms to record injuries to mail carriers using the human transporter.

What Managers Can Do

- The Post Office should make more jolt and vibration measurements and closely watch the health of mail carriers using human transporters.
- Continue to make improvements to the human transporter by redesigning the mail carrier bins, and making it easier to change the batteries.
- Make it easier to carry the human transporter on the long life vehicle.

What the Employees Can Do

- Follow the procedures for using the human transporter that they were taught during training sessions.
- Try to avoid bumps and debris while driving the human transporter to deliver mail.
- Report to management any safety and health concerns you have using the human transporter.

CDC Workplace Safety and Health

What To Do For More Information:
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National Institute for Occupational Safety and Health NIOSH

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SUMMARY

On April 29, 2002, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from the Director of Safety and Health of the National Association of Letter Carriers (NALC) in Washington, D.C. The HHE requesters wanted NIOSH investigators to evaluate whether use of a personal human transporter (HT) to deliver mail presented health hazards or risk of injury to its member.

On June 24, 2002, an opening conference took place in Washington, D.C. The meeting was attended by NIOSH investigators and representatives of the United States Postal Service (USPS), the NALC, and the Segway corporation, manufacturer of the HT. During July 15-18, 2002, NIOSH investigators evaluated the HT in Norman, Oklahoma. The NIOSH team included an ergonomics specialist, a noise and vibration specialist, and an epidemiologist with expertise in injury surveillance.

The ergonomics evaluation indicated that the HT is designed for and can be adjusted to fit the size range of most mail carriers who would use it. Mail carriers at the far end of the spectrum of height and weight may not be able to comfortably use the HT. The analysis of videotapes taken during the evaluation indicated that improvements to the HT could and should be made, but these would affect the usability and efficiency more than reduce the risk of injury to the worker.

The whole-body vibration evaluation indicated that postal employees are exposed to measurable levels of whole-body vibration while using the Segway™ HT. The greatest weighted and peak acceleration levels were from head-to-toe, which occurred while traveling over bumps in streets, sidewalks, or driveways and travel over lawns. However, since little of the published epidemiological research on vibration effects is specific to people who are exposed to whole-body vibration while standing on a movable vehicle, it could not be determined if the health of the employees would be compromised from the use of the Segway HT.

The epidemiology/injury surveillance evaluation indicated that existing accident report forms, if completed and available, contain useful data regarding safety aspects of the HT. If these forms are filled out in detail after accidents occur, no new procedures would be needed to implement a surveillance system for tracking HT accidents during mail delivery.

NIOSH investigators conclude that using a HT to deliver mail may result in harmful vibration and jolts to mail carriers but that there is lack of sufficient comparison data or standards to determine the extent of the hazard. The HT can be adjusted to fit most mail carriers, so there should be little additional risk of injury from design aspects. If the HT is used to deliver mail, the USPS should make more vibration measurements and establish a surveillance system for tracking the health status of workers using it. Additional recommendations pertaining to the use of the HT to deliver mail are contained in this report.

Keywords: SIC 4311 (The U.S. Postal Service), ergonomics, injury surveillance, vibration exposure, mail delivery, Segway Human Transporter, musculoskeletal disorders

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INTRODUCTION

On April 29, 2002, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from the Director of Safety and Health of the National Association of Letter Carriers (NALC) in Washington, D.C. The HHE request pertained to the alpha tests being conducted by the United States Postal Service (USPS) to determine if mail could be delivered safely and efficiently using a Segway™ Human Transporter (HT) on delivery routes throughout the country. The HHE requesters wanted NIOSH investigators to evaluate whether or not use of the HT presented health hazards or risk of injury to its member mail carriers. Potential health hazards contained in the HHE request included fatigue and tension from having to concentrate while operating the HT and wear and tear on the body from riding the vehicle over the many surfaces and terrain encountered while delivering mail.

On June 24, 2002, an opening conference took place in Washington, D.C. The meeting was attended by two NIOSH investigators and representatives of the USPS, the NALC, and the Segway corporation. The purpose of the meeting was to discuss the evaluation that was to be conducted by NIOSH.

During July 15-18, 2002, NIOSH investigators evaluated the HT at the Norman, Oklahoma, test site. The postal facility in Norman was one of five locations where use of the HT to deliver mail was being evaluated by the USPS. The others were Memphis, Tennessee; City Island (Bronx), NY; Phoenix, Arizona; and San Francisco, California. Prior to the HHE request, the USPS had conducted feasibility tests in Tampa, Florida, and Concord, New Hampshire.

The NIOSH team included an ergonomics specialist, a noise and vibration specialist, and an epidemiologist with expertise in injury surveillance. The investigation consisted of an evaluation of the ergonomics aspects of the HT unit, measurement of the vibration at the base of the HT during mail delivery, and a review of medical records and injury reporting procedures used at the facility. Informal interviews of the postal workers using the HT were also conducted by the NIOSH team.

BACKGROUND

The Segway HT was first introduced in December 2001 on ABC's *Good Morning America*. Prior to its introduction, the developers of the HT had been planning feasibility trials with the USPS and the Atlanta, Georgia, police department. The USPS was interested in delivering mail with the HT as part of its continued efforts to improve efficiency and cut costs. The feasibility tests in Tampa and Concord were successful enough to justify further testing at the five selected sites.

The base of the Segway is comprised of two wheels situated on each side of a platform. The rider stands on the platform and grasps a T-shaped handlebar. The personal Segway (p-series) model resembles a push lawn mower. The Segway, a self-balancing unit, uses motors, computer processors, and gyroscopes to mimic human equilibrium. Riders can propel the scooter by grasping the handlebars and gently leaning forward or backward, and stop it by standing straight. The top speed of a Segway HT is 12 miles per hour (mph) and can be adjusted depending on which key is placed in the ignition module. During the testing in Norman, Oklahoma, the key which limits the top speed to 9 mph was used.

The business (e-series) Segway , which was used by the USPS in its tests, weighs 95 pounds and has a range of about 17 miles per battery charge, a payload of 325 pounds, and a zero turning radius. The 40 units purchased by the USPS were equipped with two side carriers and one front carrier. The units also had an adjustable-height handlebar, and some had kick stands. Figure 1 shows a comparison of the basic e-series HT to the version of the HT used during the test in Norman, Oklahoma.
The sites selected for testing were all "park and loop" residential delivery routes, each with about 500

delivery addresses. The anticipated benefits of the HT in mail delivery were that letter carriers would not have to carry approximately 35 pounds of mail on their shoulders, more mail could be loaded onto the Segway to reduce the number of trips back to the truck to get more mail, and travel time between successive delivery residences would be reduced.

Because the "park and loop" style of mail delivery requires that letter carriers load a mail truck (usually the "long life vehicle" or LLV) and drive to their route, a method of transporting the Segway to the mail routes was needed. Originally, the HT was loaded into the cargo area of the LLV, but by the time of the NIOSH site visit, which was the fifth week of a six-week evaluation in Norman, Oklahoma, a ramp system attached to the back of the LLV had been developed (Figure 2). During the tests, USPS data collectors followed the mail carriers on their routes and logged delivery times and other mail delivery statistics.

METHODS

Whole-Body Vibration

Vibration acceleration measurements were collected on four different HT units that had been assigned to postal workers delivering mail on their routes. Each HT had a different mail delivery route serviced by four different letter carriers. Space limitations on the unit determined how much sampling instrumentation could be placed by NIOSH investigators on it and still allow the employee to complete their mail delivery tasks. Acceleration data were collected with a Larson Davis Human Vibration Meter (Model HVM100; North Provo, Utah). Triaxial accelerometers mounted in a rubber disk (PCB Piezotronics Model 339M19; Depew, New York) were fastened to the platform of the Segway HT with four pieces of double-sided carpet tape. The cable connecting the disk to the HVM100 was secured with wire wraps around the vertical post and the HVM100 was placed in one of the side compartments of the mail container near the letter carrier's hands. The triaxial accelerometers were calibrated by a factory authorized laboratory just prior to the evaluation and the determined voltage sensitivities were used to calibrate the HVM100.

The HVM100 was set to two different criteria for vibration measurements on each of the four HT units. The first criterion used the weighting functions specified by the International Organization for Standardization (ISO) International Standard for evaluation of the comfort of a standing person.[1] This criterion uses a weighting function (W_d) for the x-axis (belly-to-back) and y-axis (side-to-side) and a weighting function (W_k) for the z-axis (head-to-feet) over the frequency range of 0.4 Hertz (Hz) to 100 Hz. Both root-mean-square (rms) and peak acceleration values were calculated over a 30-second averaging period and stored in the vibration meter. The meter was set to the autostore mode so that each 30-second averaging period was stored over a 1-hour measurement period. The second criterion used a flat weighting function on each of the three directional axes. Both peak and rms acceleration values were calculated and stored over 30-second averaging periods for an entire hour of measurements. In cases where the mail delivery route was not long enough to complete one hour of data collection, the HVM100 was stopped when the letter carrier completed that portion of the route.

Ergonomics

The ergonomics evaluation consisted of a comparison of the physical dimensions and adjustability features of the HT to what is described in the ergonomics literature as acceptable to the various percentiles of the adult population. Analysis of video tapes taken during the evaluation served as a means of determining if use of the HT to deliver mail was associated with any postural demands (excessive reaching, awkward body positions or wrist postures) that would not occur during traditional mail delivery (see Figure 3).

Interviews

Each of the four mail carrier participants was interviewed informally after their day of evaluation. A list of questions that served as a guide to the interviewers can be found in the Appendix.

Human Transporter Injury Surveillance

To determine if it was feasible or necessary to design and implement a separate surveillance system for tracking future injuries and accidents involving use of the HT, blank forms routinely used by the USPS to record data on carrier activities were reviewed. These forms were obtained from the USPS Inspector/Manager in Norman, Oklahoma.

EVALUATION CRITERIA

Whole-Body Vibration

In the United States, it has been estimated that 8 million people are exposed to occupational vibration, with 7 million exposed to whole-body vibration and the remaining 1 million exposed to hand-arm vibration.[2] Workers who are exposed to whole-body vibration include truck and bus drivers, heavy equipment operators, farmers, civilian pilots and flight crews, and train locomotive operators. The National Occupational Exposure Survey estimates that 1.08 million workers from 42 different 2-digit Standard Industrial Classification (SIC) codes are exposed to whole-body vibration.[3] These latter estimates include only the 3- and 4-digit SIC codes surveyed within the 2-digit SIC. Not all SIC codes were included in the NIOSH survey. The largest categories of workers exposed to whole-body vibration were in heavy construction contractors (SIC 16), special trade contractors (SIC 17), and trucking and warehousing (SIC 42).

Whole-body vibration initially received attention from the military, which was concerned with the effects of vibration on the completion of their missions.[4,5] The concern for most occupational exposures involves acute effects which can affect worker safety, and chronic effects impacting workers' health.[6,7] An example of an acute effect is whole-body vibration that results in a driver losing the grip on a steering wheel, potentially leading to an accident. Most of the chronic effects of whole-body vibration which have been looked at are concerned with changes in the spines and backs of affected workers. Strong evidence of an association between whole-body vibration and low-back disorder was found in 15 of 19 studies reviewed by NIOSH. Both experimental and epidemiological evidence suggest that whole-body vibration may act in combination with other work factors, such as prolonged sitting, lifting, and awkward positions, to cause increased risk of back disorders.[8]

Neither NIOSH nor the Occupational Safety and Health Administration (OSHA) have published exposure limits for whole-body vibration. The American Conference of Governmental Industrial Hygienists (ACGIH®) has a Threshold Limit Value (TLV®) for whole-body vibration that measures rms acceleration in meters per second per second (m/s^2) for the one-third octave bands from 1 Hertz (Hz) to 80 Hz.[9] The one-third octave bands are weighted the same for the x- and y-axes but differently for the z-axis. The x- and y-axes are maximally sensitive at the frequencies of 1 to 2 Hz, while the z-axis is most sensitive between 4 Hz and 8 Hz. These most sensitive bands correspond to the natural resonances of the human body when it is vibrated in these directions. Resonance is the condition where vibration is optimally transmitted from the vibrating source to the person, with the individual actually amplifying the acceleration, possibly exacerbating the effects of the whole-body vibration.[10] Acceleration measurements are simultaneously collected in each of the three orthogonal axes and compared to the TLV's two weighting functions. The criterion has exposure time limits from 1 minute to 24 hours that correspond to the rms acceleration measured at each one-third octave band. The TLV also presents formulas to calculate the single-vector sum of the weighted accelerations from all three orthogonal axes. According to the ACGIH TLV, this single value of the sum of the weighted accelerations can then be compared to the Commission of the European Communities (CEC) directive.[11] Specifically, the directive requires a daily exposure limit value standardized to an 8-hour reference period of 1.15 m/s^2 and a daily exposure action value of 0.5 m/s^2 for the same standardized period. Once the exposure action value has been exceeded, the employer is to establish a program of technical and organizational measures to reduce exposure to mechanical vibration. The program can include changes in work practices, new equipment that produces lower levels of vibration, and training programs to instruct workers in the use of their equipment to safely reduce vibration.

The ISO has defined methods for the measurement of periodic, random, and transient whole-body vibration to indicate the degree to which vibration exposure will be acceptable.[1] The standard presents different weighting factors of one-third octave bands for the frequency range of 0.5 to 80 Hz in each of the three orthogonal directional axes. The principal weighting curves vary depending on whether the standard is being applied to health, comfort, or perception guidelines and whether the worker is seated, standing, or recumbent. As is the case with the ACGIH TLV, the weighting curves are maximally sensitive at the natural resonance of the human body, 1 to 2 Hz in the x and y directions, and 4 to 8 Hz in the z direction. The standard contains informative guides to the effects of vibration on health, comfort, and perception in a series of appendices attached to the standard. The guidance on health effects is primarily intended to reduce the risk of injury to the lumbar spine and the nervous system. A health guidance caution zone is presented in the standard to which the rms value of the frequency-weighted accelerations can be compared for varying exposure durations from 10 minutes to 24 hours. The lower boundary of the health guidance caution zone runs from approximately 3 m/s^2 for 10 minutes or less to 0.25 m/s^2 for 24 hour exposures.

Ergonomics

Overexertion injuries and musculoskeletal disorders such as low back pain, tendinitis, and carpal tunnel syndrome, are often associated with certain job tasks: (1) repetitive, stereotyped movement about the joints; (2) forceful manual exertions; (3) lifting; (4) awkward and/or static work postures; (5) direct pressure on nerves and soft tissues; (6) work in cold environments; or (7) exposure to whole–body or segmental vibration.[8,12,13,14]

The risk of injury appears to increase as the intensity and duration of exposures to these factors increases and recovery time is reduced.[15] Although personal factors (e.g., age, gender, weight, fitness) may affect an individual's susceptibility to overexertion injuries/disorders, studies conducted in high–risk industries show that the risk associated with personal factors is small compared to that associated with occupational exposures.[16]

In all cases, the preferred method for preventing/controlling work–related musculoskeletal disorders (WMSDs) is to design jobs, work stations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker. Under these conditions, exposures to task factors considered potentially hazardous will be reduced or eliminated.

The primary ergonomic risk factor of concern in this study was awkward and/or static work postures. It was presumed beforehand that if the HT could not be adjusted to fit the physical size of various percentiles of the general population or if mail carriers approached a mail box while standing on a HT instead of walking as is customary, awkward body postures would result.

RESULTS

Whole-Body Vibration

Four letter carriers were observed for two hours each. The HVM100 was placed on the HT and one hour of weighted and one hour of unweighted (flat) data were collected and stored for analysis. During the observations, videotape records of the carriers' activities were made to correlate with the acceleration data. The overall results are shown in Table 1. All of the measurements were highest in the z-axis, ranging from 0.47 m/s^2 to 1.99 m/s^2 for the unweighted accelerations and from 0.97 m/s^2 to 1.67 m/s^2 for the weighted accelerations. The peak values were also greatest in the z-axis, ranging from 17.2 m/s^2 to 39.6 m/s^2 for the flat measurements and from 13.0 m/s^2 to 19.4 m/s^2 for the weighted acceleration measurements. The associated crest factors (ratio of peak to rms) for the four Segway units were 11.0 and 11.4 in the weighted and unweighted z-axis for #34, 7.8 and 16.3 for #08, 17.7 and 36.6 for #20, and 11.9 and 19.9 for #S2.

The videotapes of the letter carriers on their Segway units were viewed and the activities performed by the employees were noted for each 30-second acceleration measurement period. Major activities included travel on streets, lawns, sidewalks, and driveways, mounting and dismounting the HT, and idle time when the unit was not in motion. Other notable activities included driving the HT over bumps, battery changes, and moving the Segway up or down the LLV's ramp. Each instance of an activity was checked on the data sheet when observed during the 30 seconds and the results were tabulated (Table 2). In this analysis, it is possible for each of the activities to occur during the 30-second period, with multiple occurrences of a single activity also possible. Three of the eight observation periods were less than one hour because of the logistics of the mail carrier's route. The route also determined the amount of time spent on each activity, with three of the four routes characterized as suburban with long driveways and few sidewalks. The mail carriers on these routes would generally travel the streets until reaching the home's driveway. The fourth route (Segway unit #08) was more urban with sidewalks in front of the houses parallel to the streets. The letter carrier on this route seldom used the street to deliver the mail.

If a single activity dominated a 30-second period, it was scored positive for that activity. If more than one activity occurred during the observation, then no category was scored positive with the exception of driveway and street activity both occurring in the same period. The mean acceleration values and standard deviations for each activity were calculated for both the weighted and flat measurement conditions in the z-axis and are presented in Figures 4-7, which represent the four Segway units. Each activity was not observed for each measurement period and for instances where only one observation of an activity was seen, there is no standard deviation given on the figure. The greatest mean acceleration values were measured at approximately 2 m/sec^2 (which is equivalent to the m/sec/sec metric on the figures). Travel on lawns and over observable bumps generally were found to have the greatest amount of vibration in the z-axis.

Ergonomics

Figure 1 shows a comparison between the HT with cargo carrying accessories and the modified HT the USPS used in Norman, Oklahoma. The dimensions of the modified HT are shown in Table 3.

The main dimensions of the HT used in Norman that could influence the comfort and usability for letter carriers of various sizes are the height adjustment of the handle bar, the height and size of the mail carrier bins, and the length and diameter of the handle grips.

Handlebar Height

In general, for standing tasks, work should be situated 2 inches to 3 inches below elbow height for light work, lower than that for heavier work, and slightly above elbow height for precision work.[17] One source of worker anthropometric data reports elbow heights for the 5th percentile female and the 95th percentile male to be 38.6 inches and 47.3 inches, respectively.[18] Another source reports standing elbow height in a 5th to 95th range of a 50-50 mix of males and females to be 37.9 and 45.8 inches, respectively.[19] Subtracting 3 inches from the extremes of these values would result in a desired adjustability range for the HT of 34.9 inches to 44.3 inches. From Table 3, it can be seen that the actual adjustability range of the handle bar for the HT varies from 32.5 to 42 inches. Another way to evaluate handle height adjustability is to use anthropometric correlation statistics. It is estimated that standing elbow height is 0.63 times stature.[20] Using this method, a female would have to be fewer than 56.3 inches tall (< 1st percentile) and a male would have to be taller than 71.5 inches (85th percentile) to be out of the calculated range.[21] Table 4 shows the height of the four participants in the study, their percentile heights, their predicted ideal handle height based on the above correlation between height and standing elbow height, and the height of the handle bar that they chose while using the HT to deliver mail.

Analysis of the video tapes indicated that all four letter carrier participants selected handle bar heights that were below their elbows, were well within the adjustability range of the HT, and from Table 4, were below what anthropometry would have predicted, with the discrepancy being greatest for the tallest mail carriers. It appears the workers felt control of the handle bar was important so they chose lower handle bar positions to achieve that end.

Side Carriers

Unlike the handle bar, the side mail carriers were not height adjustable. They were fixed at 35 inches (about 28 inches from the HT platform) and 13 inches deep. The dactylion height (measure from the floor to the tip of the fingers while standing) range for the 5th percentile female and the 95th percentile male is 21.7 inches and 29 inches, respectively. The reach to the bottom of the side mail carrier, 15 inches above the HT platform, is about 6 inches lower than the 1st percentile female dactylion height of 21 inches.

These measures indicate that the side carriers could not be used by individuals of any height without bending in some way, either at the knee to lower the hands or the trunk to reach into the carriers, neither of which could likely be accomplished while moving on the HT. Analysis of the video tapes indicated that the mail carriers did not use the side carriers for mail delivery except for large bulk items such as catalogs or small parcels. Most often, they loaded the side carriers with mail, and then transferred mail to the front carrier at various mail stops. That is, mail was delivered from the front carriers, and the side carriers were used for "carrying cargo." Another reason the side carriers were seldom used was because the spare batteries were carried in them. The added weight of the batteries served to stabilize the HT by offsetting the weight of the front carrier, which was 1 inch longer than wide, and also raised the bottom of the side carriers by virtue of being in them. Still, the workers could not effectively use the side carriers for other than cargo due to the small opening and the long reach. Even with the top of the carrier expanded fully, it was difficult for the workers to retrieve mail from the bottom.

Front Mail Carrier

The front mail carrier was a three-pocket bin mounted in front of the handlebar. The dimensions were 14 inches long and 13 inches wide. The compartment closest to the mail carrier was the deepest at 7 inches, the second was 6 inches deep, and the one furthest from the worker was 5 ½ inches deep. The angle of the front carrier increased with its length to allow for easier access by the workers (see Figure 1). The furthest compartment was about 3 inches higher than the handle bar. The front mail carrier was the one the workers delivered mail from, adding mail to it from the side carriers as deliveries were made. The compartments seemed easy for the mail carriers to reach, but their location blocked the view of the ground directly in front of the HT as it was driven, making it more difficult to see hazards.

Hand Grips

For a cylindrical handle, a diameter of about 1.5 inches is considered to be the most efficient and least fatiguing to the hand.[22] Handle length should be such that it spans the fatty tissue of the hand and not dig into the soft tissue in the middle of the hand. Hand breadth for the 5th percentile female and the 95th percentile male is about 2.8 inches and 3.8 inches, respectively.[23] A comfortable handle length for most adults is somewhere between 4 and 5 inches.[24] Comparison of these values to the grip measurements listed in Table 3 indicates that the design of the HT would be suitable for most workers.

Other Design Aspects

Changing the Batteries

Replacing the batteries involved stopping the HT, placing it in a disabled mode, removing the mail from the side carriers, retrieving the batteries and the cordless screwdriver, setting the HT on the ground, removing the screws (4 per battery, 2 battery halves), positioning the charged batteries, replacing the screws, restoring the HT to its upright position, restarting the motor, and placing the spent batteries and mail back into the side carriers. Each battery half weighed about 11 pounds. The batteries can be replaced in about 2 ½ to 3 minutes, and total down time can range from 4 to 6 minutes. During the course of the NIOSH study, the batteries were replaced once for each mail carrier observed.

Transport Ramp

The HT is carried by the LLV by means of a platform attached to the rear frame, 17 inches above ground level. The HT is placed on the platform by means of a retractable dual ramp. The HT can be dragged up the ramp or "walked" up with the HT in "follow mode," one of the many selections provided by the unit's control switch. The HT can go up and down the loading ramps with the left side carrier on, but the right side bin must be removed for clearance. It is easier to lock the ramps in the vertical position if the left carrier is also not on the HT.

It seemed fairly easy for the mail carriers to guide the HT up to the platform in "follow mode," but since the unit is on, it may rock back and forth when it reaches the platform, requiring the attention of the mail carrier. The HT must also be controlled by the worker as it is guided down the ramps. It is easiest to place the ramps on a curb, but the HT can be guided down the ramps onto any flat surface.

At the time of the NIOSH evaluation, the transport platform had been in use for only a few days. Having to remove the side carriers before going up the ramp seemed like a nuisance and added to the work load of the mail carrier. Likewise, when the right side bin remained on the HT to stabilize the unit as it was being guided up the ramp, the result was an above shoulder lift to remove the bin once the HT was secured on the platform.

Depending on the height of the handlebar adjustment, the front mail bin could block the view of one or more of the four vertically-situated rear lights on the LLV. Also, the placement of the transport platform on the right side of the truck blocked one half of the access to the rear of the truck where the mail is stored during transport with the LLV.

Effect of the HT on Work Load and Posture

The physical advantages of the HT for the mail carrier are the relief from walking and carrying a sack of mail that typically weighs about 35 pounds. This could have an effect on the long term incidence of foot, leg, back, and shoulder musculoskeletal disorders. In the near term, use of the HT to deliver mail could have a positive or negative effect on the postures assumed by the mail carriers as the mail is delivered to specific locations (Figure 3). Analysis of the video tapes taken during the NIOSH evaluation indicated that in some cases the mail carriers reached a little farther to deliver mail to a box while standing on the HT. In other cases, delivering mail while on the HT made the task easier and faster, most notably in instances where the mail slot was located on a garage door, enabling the mail carrier to drive up, drop the mail into the slot, and drive to the next house. Even in these cases, though, the mail carrier could not always get as close to the mail box or slot as would be possible on foot, and because being on the HT elevates one's stature, the worker often had to reach and/or bend over to put mail into the slots. Reaching and bending were greatest on those occasions when mail was taken from the side carriers instead of the front carrier. However, most often the mail carrier had to drive as close to the house as possible, get off the HT and deliver the mail. In these cases, there would be no difference in work load and posture between delivering mail with the HT or as done conventionally, except that the mail bag is not being carried.

Analysis of the videotapes also indicated that being on the HT seemed stressful to the lower leg. The lower leg muscles appeared to be most stressed when the HT was driven on grass or over bumps, and when the mail carriers dropped their hips down to slow the momentum of the HT when making turns or when negotiating the transition between a driveway and the street.

Interviews

Two of the mail carriers studied were men and two were women. They ranged in height from 60.5 to 71 inches. The four subjects' weight range was from 95 to 180 pounds, and their experience as mail carriers ranged in years from 3 to 25. They were selected to be in the USPS time and motion studies because of the mail routes they were delivering, not for any reason related to gender, age, prior injury record, or efficiency as a mail carrier. The NIOSH interviews lasted between 15 and 30 minutes. Main topics discussed during the interviews are contained in the Appendix.

Each mail carrier reported they had received two days of training on the HT, three had been in the study since it began and the other had missed two of five weeks. Three of the four mail carriers reported they had fallen off or lost control of the HT during the initial days of the evaluation.

In general, all four mail carriers liked the HT, two wanted to use it exclusively, but none thought it would be fully deployed in the Norman, Oklahoma, delivery area. None reported any new aches or pains from using the HT, and one reported relief from foot problems experienced prior to using the HT. No one felt mentally fatigued from using the HT or reported any motion sickness, but all admitted that the HT required their constant attention to avoid the pitfalls of the surfaces which they traversed.

Other comments made are listed below. If more than one worker made the same comment, that number appears in parentheses.

- Not sure the HT will save time (2)
- HT not safer, but healthier
- Like not carrying mail (2)
- Don't like wearing a helmet (2)
- HT needs shocks
- Would like a lift on the LLV instead of ramp (2)
- Can not keep mail dry in the rain
- Cool in summer, but concern about winter chill
- Lower legs get tired (2)
- Don't like side carriers
- Feels natural to be on the HT (2)
- Feel good after a day of work, more energy
- I could make it to retirement using the HT (2)
- Segway is a good first effort, very elegant machine
- Flaps should go inside out on bags, not outside in, don't need to be expandable
- Front carrier throws off balance of HT, bigger than it has to be, should have cargo nets on side
- Going to my truck every 15 minutes warms me up in the winter
- Riding HT requires development of new driving skills
- There may be a loss of physical fitness from riding instead of walking
- Higher side bags would interfere with body space, why not have conventional mail tubs on side

Human Transporter Injury Surveillance

The following forms were reviewed by the NIOSH epidemiologist during a meeting with the Inspector/Manager in Norman, Oklahoma. The purpose of the meeting and the form review was to become familiar with methods and procedures in use to record injuries and accidents at the USPS for purposes of determining if alternative procedures would be feasible or necessary if the HT were to be deployed for regular mail delivery.

Form 1769 "Accident Report" is used by the USPS to record information on accidents and injuries including location and conditions, persons involved, a description of the event, and suggested preventive actions. It has space for a map of the incident. It is used by the USPS instead of forms OSHA 101 and OSHA 301. Items 44, 45, and 46 on Form 1769 relate to the nature and severity of an injury and the body part affected, which would be useful information in the event of an incident involving the HT.

Form CA-1 “Federal Employee’s Notice of Traumatic Injury and Claim for Continuation of Pay/Compensation” is used when an employee reports an injury, and as a result requests continuation of compensation. Form CA-1 is usually accompanied by Form 1769 for the incident associated with the injury.

Another form, CA-2 “Notice of Occupational Disease Claim for Compensation” is used to record work-related disease or illness. This form would probably not be needed in a system to record HT safety-related incidents, but could still be used to record chronic MSD thought to be from HT.

Form CA-16 “Authorization for Examination And/Or Treatment” authorizes a medical facility or physician to provide medical service with regard to a specific disease or injury. Part A is completed by the authorizing official, and Item 5 should contain a description of the injury or disease. Part B is completed by the attending physician and Item 15 should contain a history provided by the employee. These and some additional items on the form would be useful in an accident surveillance system.

Form CA- 17 "Duty Status Report" was completed for carriers using the HT. This form specified the usual work requirements of the employee. For the HT trial, the postal inspector specified a Maximum Lifting and Carrying Weight of 35 pounds (both continuous and intermittent) for six hours a day. It also pre-specified sitting (two hours intermittent), standing (six hours continuous), walking (six hours continuous), as well as other requirements including twisting (five hours intermittent), pulling, pushing, grasping, and outdoor work involving temperature extremes and high humidity. The total number of hours exceeds the daily duty hours since some activities occur simultaneously.

While workers were being trained to use the HT, some minor incidents occurred. Some of these occurred during initial training while maneuvering between traffic cones, and others occurred on mail routes, usually upon encountering hidden sticks or crevices on lawns. All such incidents were reported on Form 1769 and CA-1.

Other forms of possible value for an HT accident surveillance system might include PS Form 4584 "Observation of Driving Practices," PS form 1700 "Accident Investigation Worksheet," and Form 1767 "Report of Hazard, Unsafe Condition or Practice."

Three forms, 1769, CA-1, and CA-16, are most likely to have useful information regarding occupational injury or safety problems related to use of the HT during the USPS trials.

DISCUSSION

Whole-Body Vibration

The logistics of this evaluation partly dictated what could be accomplished in the measurement of whole-body vibration to the postal employees who were chosen to participate in the USPS trial of the Segway HT. NIOSH investigators could not interfere with the delivery of the mail or the time-motion study that was being simultaneously conducted by the USPS. Space was very limited on the unit for vibration analysis equipment. Because of this, it was decided to use the HVM100 to collect data. It was also predetermined to set the unit for the comfort parameters stipulated in ISO 2631 for half of the trials and on a flat, unweighted function for the other half of the trials. This procedure did not allow for any spectral analysis of the acceleration levels for the individual axes as dictated in the ACGIH TLV for whole-body vibration.[9]

Also, because of the uniqueness of using the Segway HT unit to deliver the mail, it is difficult to compare the results obtained in this evaluation to any guideline or standard and conclude that there is increased risk of injury to the rider or that the unit does not increase the risk of an adverse effect on the postal employees' health. The ISO standard states that most of the guidance in Annex B describing the effects of vibration on health... "is based on data available from research on human response to z-axis vibration of seated persons. There is only limited experience in applying this part of ISO 2631 for x- and y-axes seating and for all standing, reclining, and recumbent positions." The ISO standard further limits the applicability of its evaluation method when crest factors are greater than 9. The measured crest factors in this evaluation for the weighted measurements ranged from 7.8 to 17.7 in the z-axis. The standard states that for these situations with high crest factors, the method may underestimate the severity with respect to discomfort. Finally, the multiplying factors (k) used when combining vibrations from the three orthogonal directions were set at k=1 as stipulated for evaluation of comfort for standing persons.[1] This differs from the CEC directive which uses multiplying factors of k=1.4 in the x- and y-axes as stipulated for seated subjects.[11]

In spite of these limitations, the data collected over the two days on the four Segway units does indicate that the postal employees are exposed to vertical (z-axis) vibration as they maneuver the unit. All four units had measurement periods while they were on streets, driveways, sidewalks, and lawns. There were also many periods where the units were not moving while the postal employee left the vehicle to walk to mailboxes or stood on the HT while the mail was put into mail boxes or slots. Whole-body vibration in the z-axis always exhibited the greatest acceleration values for both peak and rms measurements. For the rms accelerations in the z-axis, the values ranged from 1.0 to 1.7 m/s^2 which corresponds to the health guidance caution zones of ISO 2631 of about 1 to 6 hours of exposure per day. For the comfort reactions of seated passengers, these acceleration values fall into the uncomfortable category presented in Annex C of the ISO standard.[1] However, because of the limitations noted earlier, it cannot be determined with these data if the HT units will lead to an increased risk of adverse health effects from using them on postal delivery routes.

Ergonomics

The purpose of the NIOSH evaluation of the HT in Norman, Oklahoma, was to determine if its use would have an effect on the health status of mail carriers who had previously delivered mail on foot carrying sacks of mail on their shoulders. As noted in the Results Section, the unit seemed to have the adjustability features to accommodate the majority of mail carriers who would use it. The exception to this is the height of the side carriers, but the analyses indicated that mail was mostly delivered from the front carrier and the side carriers were used to hold the batteries and store mail until it was transferred to the front carriers. Delivering mail to slots and boxes while on the HT seemed to place the mail carriers in more awkward and extreme postures, but whether or not these instances would add to the risk of a mail carrier developing a musculoskeletal disorder is difficult to estimate because the observed norm for delivery to the mail endpoint was to get off the HT, walk to the mailbox and deliver the mail as usual. The main difference is that the mail carrier was not carrying a mail sack, which likely is a factor reducing the risk of injury. A meaningful comparison of the relative risk of injury due to postural differences could only be made on a route where most of the mail deliveries were made while the carrier was situated on the HT.

As noted in the Results Section, driving the HT seemed to considerably involve the calf muscles of the lower leg. These muscles appeared to be the main absorber of the energy transmitted to the body through the feet. The mail carriers also used their legs to control the HT and slow it down when transitioning to and from unlike surfaces. Except for two comments by the mail carriers about lower leg fatigue and one expressing a need for shock absorbers on the HT, the effect of using the HT on the lower leg muscles was not assessed by this evaluation. A non-invasive measuring technique called electromyography (EMG)[25] could be used in further studies to quantify the effect of HT use on the lower leg muscles. Using EMG, surface electrodes could be placed on the lower leg to record the amount of electrical activity of muscles during HT use. The magnitude of electrical output increases linearly as muscle activity increases and provides an objective indication of muscle fatigue. A comparison of the lower leg muscle EMG while on the HT to that while walking to deliver mail would further clarify any physiological differences that may exist between the two methods of mail delivery.

Many of the comments made in the Results Section about the design of the ramp, the method used to change the batteries, or the design of the front carriers pertained to efficiency and ease of use, not necessarily to safety and health. It would be better to have batteries that could be secured into place with a clip instead of by removing eight screws, but it is not certain that doing so would make the workers any safer. The ergonomics aspects of changing the batteries was addressed by providing the data collectors with a cordless electric screwdriver to remove and replace the screws. Likewise, it would be more convenient if the mail carrier did not have to walk the HT up and down the transport ramp and remove the side carriers to transport the HT, and it would be more convenient if the transport ramp did not block one half of the access to the rear of the LLV, but it could not be said for certain that use of an alternative design, such as a lift gate, would reduce the risk of injury to the worker.

Undoubtedly, some of the features of the HT could be improved as noted above, but it is likely that modifications and improvements will be made as the feasibility testing of the unit progresses. Ultimately the extent to which the HT is deployed (if at all) will be based on many factors such as efficiency, cost savings, and safety.

Human Transporter Injury Surveillance

Injury might occur to a HT rider from being thrown forward, to the side, or off the machine. This could occur if the HT encounters an unseen obstacle, hole, or depression. It could also occur if one wheel sticks, for example on a curb. Most injuries would probably be minor, for example sprains, strains, or contusions, and might involve the ankle, lower leg, knee, hand, or wrist. If these did not result in a lost workday they would be classified as non-injuries or first aid injuries. However there might be a possibility of more serious injury to the face or eyes. A collision between a larger vehicle such as a car and a HT could be extremely dangerous for the HT rider.

Although this report focuses on the evaluation of the HT for occupational purposes, its use has also aroused some public interest and controversy. The HT has been used by members of the current administration and by the President at his retreat home. The City of San Francisco banned the HT temporarily because of concern for public safety.[26] On the other hand, the HT has been tested and used in a variety of situations including Walt Disney World and the Atlanta Police Department. Use of the HT by the USPS would represent a large-scale interaction of the unit with the public. An accurate and thorough surveillance system to track injuries and other incidents related to HT use should be a high priority for the USPS from the standpoint of occupational and public health.

CONCLUSIONS

1. Postal employees are exposed to measurable levels of whole-body vibration while using the Segway HT. The greatest weighted rms and peak acceleration levels were measured in the z-axis, or from head-to-toe. Also, traveling over bumps in streets, sidewalks, or driveways and traveling over lawns was found to have the highest levels of vibration. The unweighted, flat functions collected on each Segway HT unit did not add any additional information to this evaluation as the values were found to be similar to the weighted functions.

2. Because of very limited epidemiological data for people who are exposed to whole-body vibration while standing on a movable vehicle, it cannot be determined if the health of the employees would be compromised from the use of the Segway HT. None of the published standards or guidelines are appropriate for this kind of whole-body vibration exposure.

3. If the USPS decides that continued use of this vehicle should proceed, then additional vibration data should be collected. A better comparison to existing

standards and guidelines can be accomplished with one-third octave data collected on the units while they travel over existing mail routes. Because additional measurement equipment would be necessary, these data could possibly be collected on Segway HT units that are not actually delivering customers' mail. Even with this more thorough analysis, there is still little or no epidemiological data on the health effects of whole-body vibration on standing subjects. The USPS would have to collect these health data over time, paying attention to changes in feet and leg muscles and joints, as well as complaints of back and neck pain.

4. The HT is designed and can be adjusted to fit the size range of most mail carriers that would use it. Mail carriers at the far end of the spectrum of height and weight may not be able to find accommodation using the HT.

5. Improvements to the HT could and should be made, but these would affect the usability and efficiency more than reduce the risk of injury to the worker.

6. Several forms used by the USPS contain useful data regarding safety aspects of the HT if completed and available. The three forms, 1769, CA-1, and CA-16 are most likely to have useful information regarding occupational injury or safety problems related to use of the HT during mail delivery. If these forms are filled out in detail after accidents occur, the data obtained could be used to implement a surveillance system for tracking HT accidents during mail delivery.

RECOMMENDATIONS

- Continue to collect vibration data from the Segway HT unit as it is used in the field. Similar methods to the ones used in this evaluation that collect only weighted acceleration levels along with more elaborate procedures that collect spectral information are both warranted. The unweighted, flat functions that were collected in this evaluation are probably not needed since there are no published standards for comparison.

- If use of the Segway HT unit is continued, then a system of tracking injuries, accidents, and associated musculoskeletal disorders should be implemented. Attention should be given to muscle and joint complaints and problems in the feet, legs, back, and neck. Also, symptoms consistent with low frequency, whole-body vibration that leads to motion sickness should be recorded.

- Evaluate the muscle activity and fatigue levels of the lower leg muscles using an objective technique like surface EMG. EMG could also be used to evaluate back, shoulder, and arm muscles while delivering mail on the HT.

- Redesign the side carriers so that their size and placement allows mail to be delivered directly from them. Design criteria would include height adjustment, convenient access without interfering with the space and vision of the mail carrier, and protection of the mail during bad weather. A design utilizing a platform onto which a mail bin filled at the Post Office can be attached, would avoid multiple handling and transfer of mail from bin to bin.

- Redesign the front carrier to be as small as needed by the mail carrier to improve vision while driving the HT, while at the same time satisfying weight distribution and balance requirements of the HT.

- Redesign the coupling mechanism used to transport the HT from the mail facility to the routes and between routes during delivery. Design criteria would include convenient attachment to the transport vehicle without need to remove mail bins from the HT, and easy access to the rear of the truck when the HT is attached.

- Redesign the method used to attach the batteries to the HT. A quick release clamp requiring no tools would be most effective.

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Figure 1: A view of the basic e-series cargo carrying human transporter (left) and the modified human transporter (right) used in Norman, Oklahoma.

Figure 2: Mail carrier guiding the HT down the transport ramp.

(a)

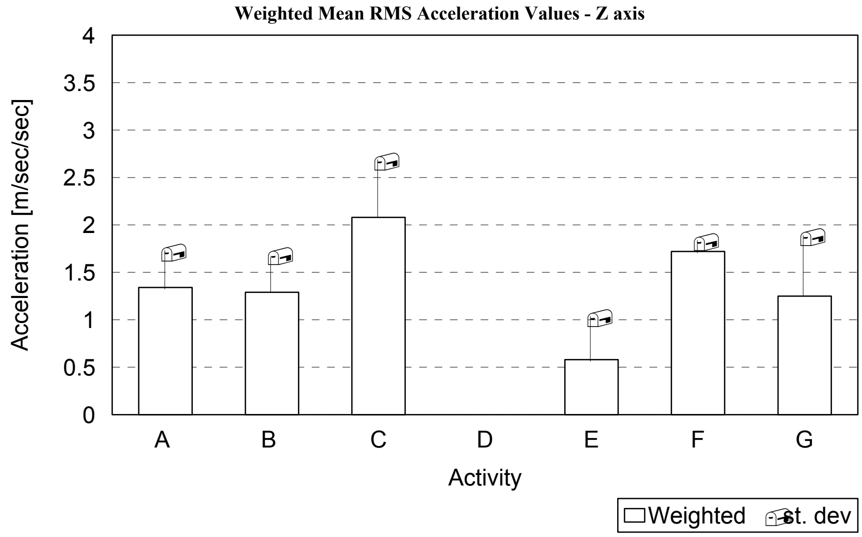
(b)

(d)

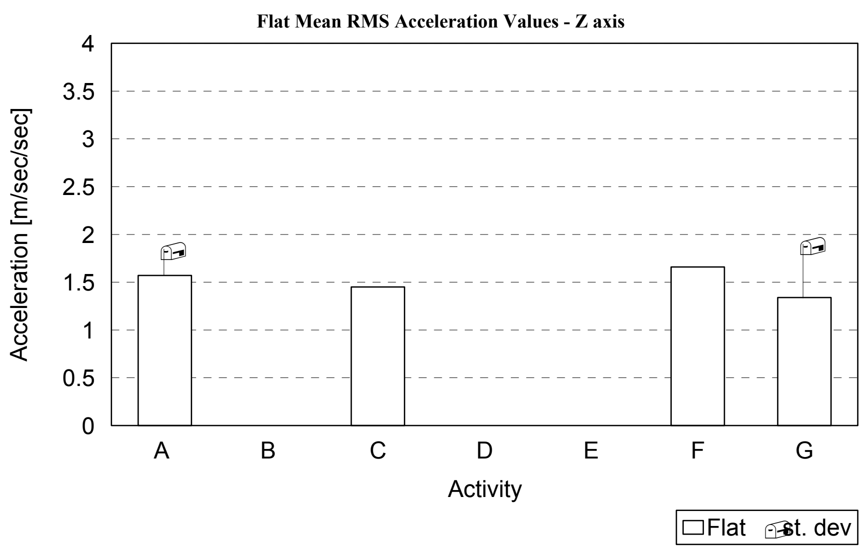
(c)

Figure 3: Neutral body postures while delivering mail on the HT (a, b); Reaching and bending to deliver mail while standing on the HT (c, d).

Figure 4
Segway Unit #34
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17. 2002

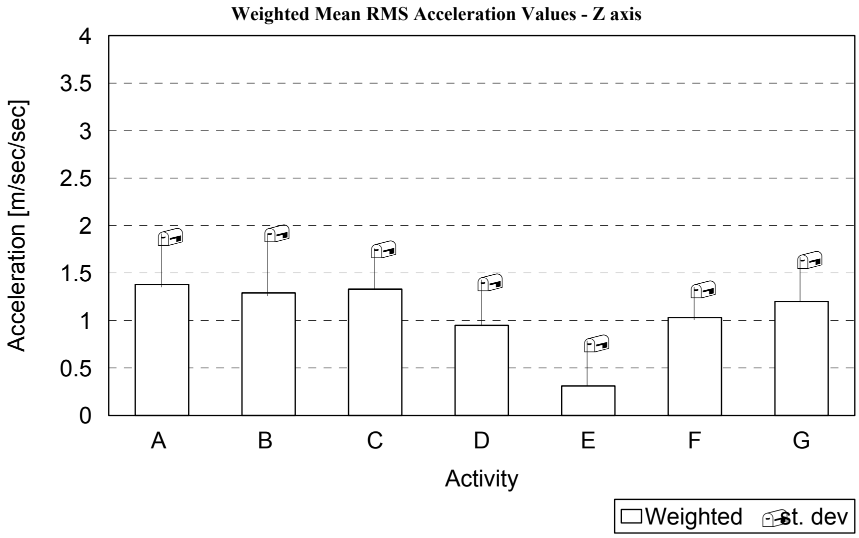


A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

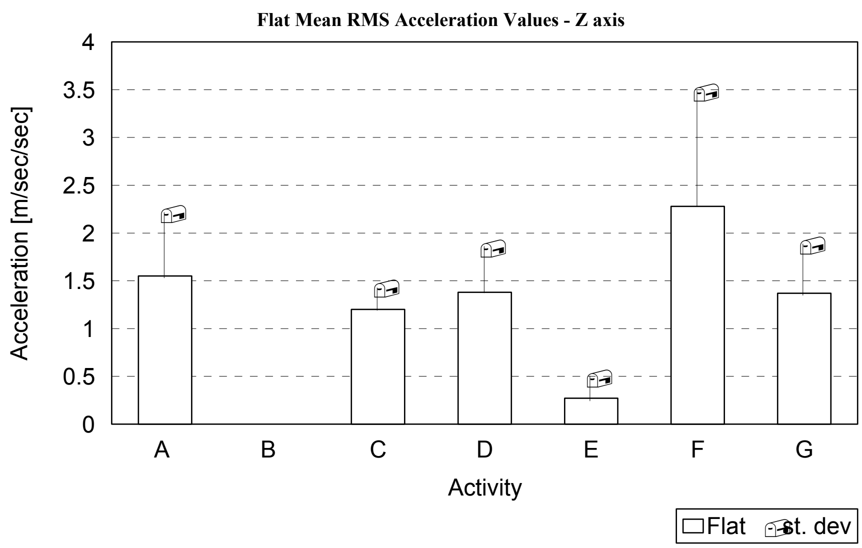


A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

Figure 5
Segway Unit #08
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17. 2002

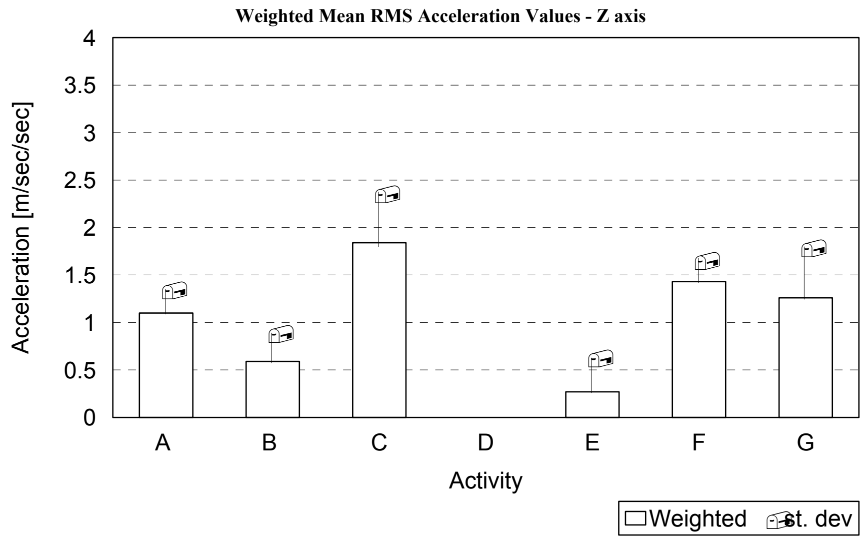


A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

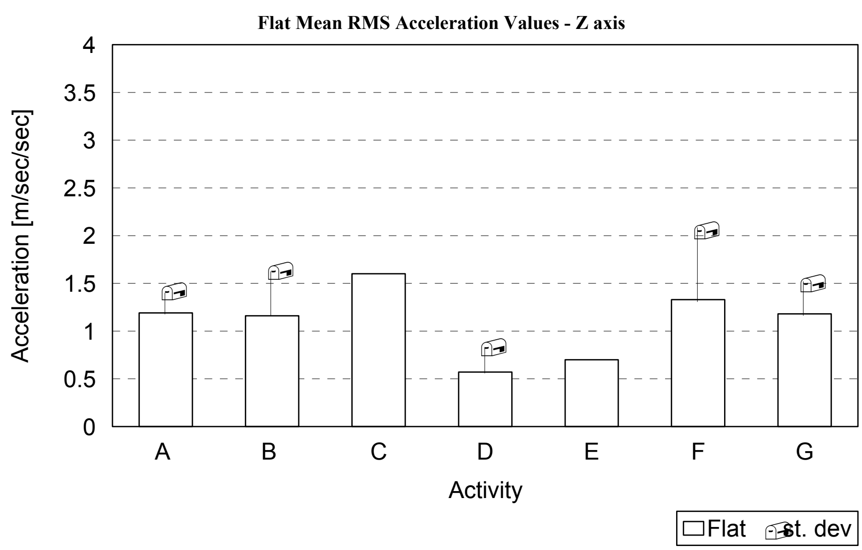


A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

Figure 6
Segway Unit #20
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17. 2002



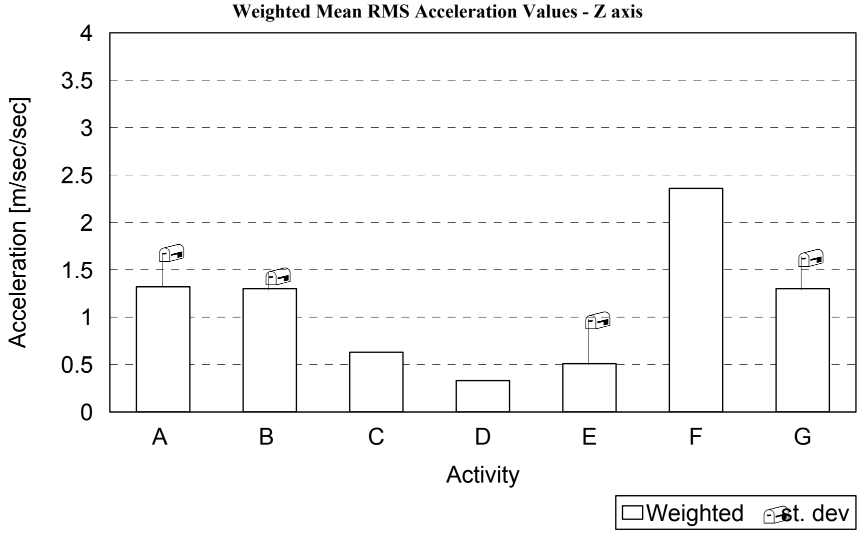
A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other



A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

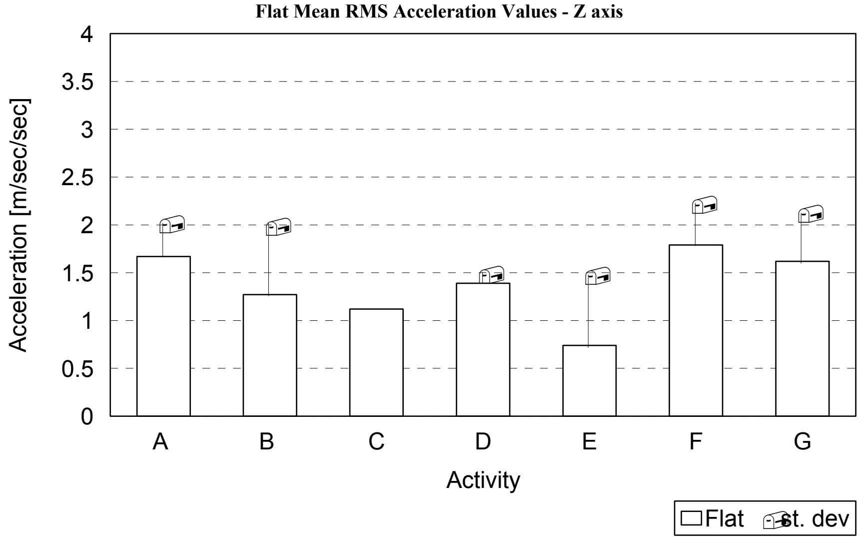
Figure 7
Segway Unit #S2
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17. 2002

Weighted Mean RMS Acceleration Values - Z axis



A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

Flat Mean RMS Acceleration Values - Z axis



A - drive & street; B - street; C - lawn; D - sidewalk; E - idle; F - bump; G - other

Table 1
Triaxial Acceleration data - Segway HT units
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17, 2002

	Unit #34		Unit #08		Unit #20		Unit #S2	
	rms [m/s^2]	peak [m/s^2]	rms [m/s^2]	peak [m/s^2]	rms [m/s^2]	peak [m/s^2]	rms [m/s^2]	peak [m/s^2]
X - axis weighted	0.65	4.15	0.41	1.85	0.62	5.92	0.50	2.13
Y - axis weighted	0.55	4.32	0.59	3.06	0.41	2.88	0.40	1.95
Z - axis weighted	1.26	13.90	1.67	13.00	0.97	17.20	1.63	19.40
X - axis flat	0.95	7.71	0.54	4.84	0.37	2.58	0.66	4.84
Y - axis flat	1.18	11.60	0.94	6.28	0.32	2.46	0.91	10.00
Z - axis flat	1.59	18.20	1.60	26.10	0.47	17.20	1.99	39.60
Sum weighted	1.51	13.90	1.81	13.00	1.21	17.20	1.75	19.40
Sum flat	2.20	18.20	1.93	26.10	0.68	17.20	2.28	39.60

rms = root mean square
m/s^2 = meters per second squared
X-, Y-, Z- axis flat = raw acceleration data
X-, Y-, Z- axis weighted = acceleration data with ISO weighting function applied

Table 2
Major Segway Activity Results - Total Instances per Observation
U. S. Postal Service
Norman, OK
HETA 2002-0239
July 16-17, 2002

Unit # /Weighting	Street	Lawn	Driveway	Sidewalk	Mount	Dismount	Idle
34 - weighted (120) *	76	34	81	9	71	70	88
34 - flat (120)	83	24	96	4	72	70	88
08 - weighted (120)	21	20	39	64	49	50	88
08 - flat (120)	10	34	46	75	53	52	106
20 - weighted (118)	64	23	78	37	44	43	98
20 - flat (109)	82	9	90	56	49	47	90
S2 - weighted (85)	68	2	67	20	47	47	80
S2 - flat (120)	95	1	91	27	57	55	99

* Number in parentheses is total 30-second observation periods.

Table 3: Human Transporter Dimensions

Component	USPS Cargo HT
Wheel Diameter, Width	18 in., 3.5 in.
Wheel Base Length	21.5 in.
Foot Pad (L x W)	15.5 in. x 14.5 in.
Side Mail Carriers (L x W x D)	17.5 in x 7 in. x 13 in. Opening can be expanded an additional 6 in. to 23.5 in., no height adjustability, fixed at 35 in. (from ground, 28 inches from HT platform)
Front Mail Carrier (L x W x D)	14 in. x 13 in. depth varies from 7 in. to 5.5 in. front to back
Center Post Height (Handlebar)	Adjustable from 32.5 in. to 42 in.
Handle grips (diameter, length)	1.5 in., 4 in.
Hand grip separation (left to right hand)	18.5 in., at end of grip, 17 in. center to center
Tire pressure (pounds)	26.5

Table 4: Study Participant Height and Chosen Handle Positions

Mail Carrier	Height (in.)	Population %	Predicted Handle height (in)	Actual Height (in)
1 (female)	64	50	37.3	35.5
2 (female)	60.5	5	35.3	32.5
3 (male)	67	25	39.2	35.25
4 (male)	71	75	41.7	35.5

APPENDIX

General Topics of Discussion with Letter Carriers Studied at Norman, Oklahoma

1. Whether or not they were the regular carrier on their route?
2. Number of weeks having used the HT?
3. Extent of training using the HT?
4. Likes and dislikes regarding the HT?
5. Suggested improvements for the HT?
6. Any accidents using the HT?
7. How do you feel after using HT - any new aches and pains? Any aches and pains that don't occur anymore?
8. Ever feel dizzy or otherwise mentally fatigued using the HT?
9. Would you like to use the HT exclusively to deliver mail?

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