Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

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To cite this article: Katharyn A. Grant , Peter W. Johnson & Trad L. Galinsky (1995) Evaluation of an Accelerometric Activity Monitor as an Exposure Assessment Tool in Ergonomic Studies, Applied Occupational and Environmental Hygiene, 10:5, 461-466, DOI: 10.1080/1047322X.1995.10387638

To link to this article: https://doi.org/10.1080/1047322X.1995.10387638

Published online: 25 Feb 2011.

Evaluation of an Accelerometric Activity Monitor as an Exposure Assessment Tool in Ergonomic Studies

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Valid and reliable methods of assessing exposures to repetitive and forceful activities are needed to address the relationship between work tasks and the development of upper extremity musculoskeletal disorders. The utility of wrist-worn activity monitors for measuring exposure to repetitive activities in hand-intensive work was examined in this study. Twenty-two grocery cashiers and ten noncashier retail workers wore activity monitors on both wrists and the left ankle during their normal work activities. Work activities were periodically observed and recorded on videotape. Data recorded by the monitors were matched against observational data. The results indicated that the monitors were effective in detecting significant work-related variations in physical activity in the three limbs studied. Compared with traditional observational procedures, activity monitoring represents a cost-effective approach to obtaining objective and quantitative information about the frequency and intensity of manual work activities over long time periods. However, observation of job activities is required to provide additional information needed for a complete job analysis (e.g., to identify tasks associated with periods of increased activity). Continuous activity recordings can be used in conjunction with work sampling protocols to examine the relationship between work-related physical activities and musculoskeletal trauma. GRANT, K.A.; JOHNSON, P.W.; GALINSKY, T.L.: EVALUATION OF AN ACCELEROMETRIC ACTIVITY MONITOR AS AN EXPOSURE ASSESSMENT TOOL IN ERGONOMIC STUDIES. APPL. OCCUP. ENVIRON. HYG. 10(5):461–466; 1995.

Musculoskeletal disorders of the upper extremities have become a leading source of concern among occupational health professionals. Evidence has accumulated which suggests that these disorders are associated with highly repetitive occupational activities, especially those involving high force, extreme joint postures, or exposure to vibration.[1,2] Previous studies, however, have not provided sufficient information for the development of dose–response models relating occupational stressors to the development of upper extremity musculoskeletal disorders among exposed workers. One obstacle in performing this type of research concerns the difficulties inherent in quantifying exposures to ergonomic risk factors.

Establishing an association between adverse health effects (musculoskeletal disorders) and poor job design factors (e.g., repetitive and forceful manual activities) requires sound empirical methods for estimating the intensity, frequency, and duration of human exposures to these work conditions.[3] Three methodologies have been applied to assess exposure to ergonomic hazards: (1) self-report methods (e.g., diaries and questionnaires), (2) observational methods, and (3) direct measurement techniques.[4] To date, none of these approaches have proven completely satisfactory for gathering reliable exposure data from a large number of workers. Establishing the validity and reliability of self-report instruments for documenting physical activity is often difficult,[5] and comparisons of questionnaire assessments with observational data frequently show little consistency.[4] Some evidence suggests that while people can readily identify the presence or absence of specific risk factors, they tend to underestimate the frequency of some activities, while overestimating the duration of others.[6] Most investigators agree that application of observational or direct measurement methods increases the quality of ergonomic exposure assessments,[4] yet these methods tend to be costly and time consuming. Indeed, time and cost constraints make it virtually impossible to perform a study in which all subjects are observed and/or monitored for any significant length of time. As a result, most researchers measure exposure in a small sample of workers and apply the results to all workers in the same job title or category. Because numerous sources of variation exist among workers employed in the same job (e.g., anthropometry, individual work habits), job title usually provides only a crude index of the hazards. As a consequence, real associations between exposures to specific risk factors and the development of upper extremity disorders may be underestimated or overestimated.

Clearly, an alternative measurement approach would enhance efforts to elucidate the relationship between work activities and musculoskeletal injuries. One possibility is the use of accelerometer-based motion recording systems to continuously record human body movements. Recent advances in microelectronics have allowed development of miniaturized, battery-powered systems with up to 32K of memory and enhanced programming capabilities. Activity monitors can be attached to most sites on the body (wrist, ankle, trunk) and are capable of making continuous recordings for up to 30 days.

Activity monitors have traditionally been used to study human motor activity in epidemiological research for purposes such as distinguishing sleep and waking states, and estimating daily energy expenditure.[7] The applicability of the technique could be extended to the quantification of manual work activities in terms of movement frequency and duration in order to determine the impact of these factors on musculoskeletal compromise. Advantages of this approach are that it does not require the constant attention of observational approaches, and it precludes the influence of biases that can affect observational and self-report data. To date, there have been no published studies that have examined the utility of accelerometric activity monitors for characterizing the nature and intensity of repetitive, manual work. Recently we have undertaken studies to evaluate the use of these devices for distinguishing among workers exposed to different levels of hand/wrist activity during their job activities. This article describes an assessment based on data obtained from a recent field study of workers in the retail food industry (SIC 541).

Retail food workers from two job categories thought to differ in terms of exposure to ergonomic risk factors—grocery cashiers and general merchandise clerks—were selected for study. Grocery cashiers often handle more than 500 grocery items per hour.[8] Tasks such as price scanning and bagging require repetitive hand/arm movements and forceful manual exertions, often combined with awkward wrist, shoulder, and trunk postures. By contrast, tasks performed by general merchandise clerks are less stereotyped and require less manual activity. Their primary job function is to provide customer service, that is, to help customers locate items in the store, to answer questions, and to handle special customer needs. Whereas cashiers perform most job activities at a fixed location (the checkstand), general merchandise clerks tend to roam about the store, performing light stocking tasks or attending to customers as needed.

The primary goal of this study was to examine the extent to which physical differences in the two jobs described above can be reflected in recorded activity data. Worker activities were observed and categorized. Data obtained from monitors affixed to workers' wrists and ankles were analyzed to determine if variations in activity levels paralleled activity differences demarcated through direct observation and videotape analysis. It was expected that, during work periods, wrist activity would be higher among cashiers than among general merchandise clerks, whereas activity levels recorded from the ankle would be higher among general merchandise clerks than among cashiers. Moreover, within the cashier group, wrist activity levels were expected to vary with the type of task being performed, with higher levels observed during scanning and bagging tasks.

Method

Work Sites

Data were collected at five medium-sized retail supermarkets and at one large combination store encompassing a full supermarket, a discount store, and a pharmacy. All of the stores were located in the Midwest region of the United States.

Subjects

Twenty-two grocery cashiers (7 men and 15 women) and ten general merchandise clerks (2 men and 8 women) were selected for inclusion in this study. Participants ranged in age from 18 to 55 years. All of the participants were right-handed and free of musculoskeletal complaints, and all had a minimum of 6 months' experience working in their current job.

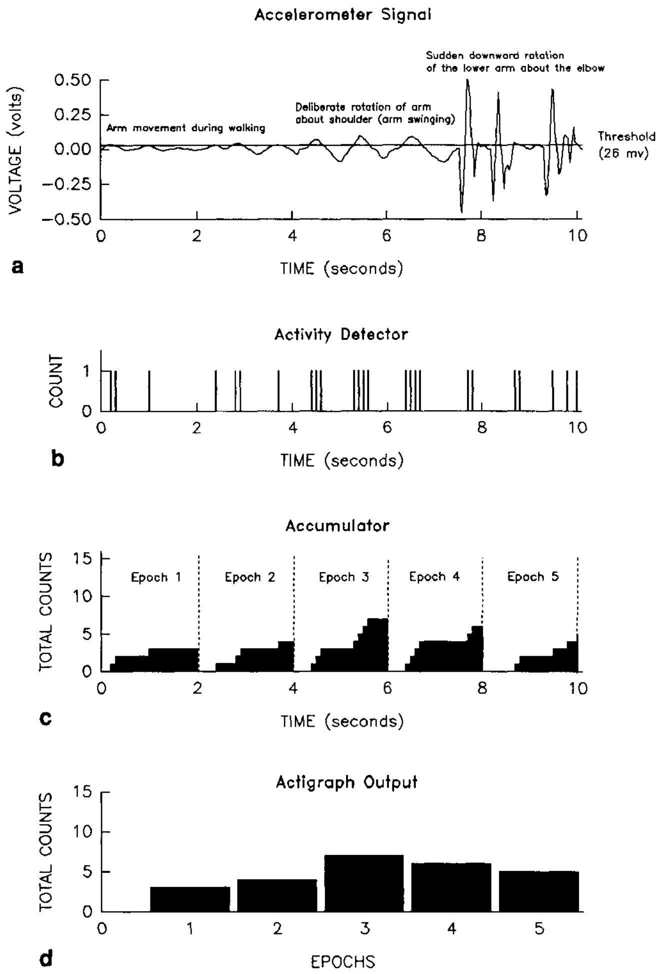

FIGURE 1. Time-above-threshold mode processing.

Apparatus

The Motionlogger Actigraph Mini (Ambulatory Monitoring, Inc., Ardsley, New York) was used to provide continuous information about wrist and ankle movement during each participant's work and break time activities. The Motionlogger Actigraph Mini weighs 57 g and is housed in a 4.5 × 3.3 × 1.0-cm wireless aluminum enclosure which is secured to the wearer's limb with velcro straps. Each unit contains a piezoceramic motion transducer (accelerometer) which produces a voltage in response to accelerations in the X, Y, or Z planes; a real-time clock to control data collection start/stop times and keep track of the time of day; and 32K of static random access memory for data storage. A computer interface is used for programming data collection specifications and for downloading data.

In this study, the time-above-threshold signal processing algorithm was used. This algorithm is illustrated in Figure 1. Analog voltage signals produced by the motion transducer (Figure 1a) are bandpass filtered (a 2 to 3-Hz passband was used in this study) and sampled at a rate of 10 Hz. At each sampling instant, the transducer voltage is compared with a user-selected threshold voltage; the current design allows the user to choose between a low threshold of 7 mV, or a high threshold of 26 mV, used in this study. The low threshold setting is often used in sleep studies when even slight movements are of interest to the investigator, whereas the high threshold setting is more appropriate for studying long excursion movements and general daytime activity. If the transducer voltage exceeds the reference voltage, a unit pulse is produced (Figure 1b). Pulses are accumulated in a counter over a preselected epoch time (2 seconds in this study; Figure 1c). When the time period expires, the total number of pulses (count) generated during the epoch interval is stored in memory (Figure 1d). These data can be downloaded to a microcomputer after data collection is completed.

The activity monitor also provides capability for event marking. A pulse is stored to memory any time a button on the face of the unit is compressed. These markers can be used to indicate the times at which predesignated or "special" events occur.

Two hand-held Sony video cameras were used to record cashiers' actions on videotape. The cameras' clocks were synchronized with the real-time clocks inside the activity monitors.

Procedure

Each participant wore three units, fastened to the left and right wrists and the left ankle, for a 3- to 6-hour monitoring period on a working day. The event marker on each participant's left wrist unit was activated at the beginning and end of each recording period. Most participants (11 cashiers and 9 general merchandise clerks) received a break from work during the recording period; hence, the event marker was activated at the beginning and end of each break interval.

Investigators observed and recorded the work activities of all participants at random intervals throughout each monitoring period. Clerks were observed four times every hour for periods of approximately 5 minutes each. Cashiers were observed continuously for a 15-minute period once every hour, and their work activities were recorded on videotape. At the completion of each monitoring period the units were removed and data were downloaded to a microcomputer.

Data Analysis

Using the event markers to identify work and break periods, each epoch during the 3 to 6-hour recording period was identified as occurring during a work or break time. Counts were summed, and means (expressed in counts/epoch) were computed for each participant at each recording site (left wrist, right wrist, and left ankle). A mixed model with two within-subjects factors (recording site and work/break period) and one between-subjects factor (job title) was used in the analysis of variance to assess the significance of the main effects and interactions. Where necessary, degrees of freedom were adjusted to correct for correlations of the within-subjects factors.[9]

Using data obtained from the grocery cashiers, an additional analysis was performed to determine if different job tasks were associated with different levels of recorded activity. Cashier work activities (recorded on videotape) were classified into one of five categories: (1) scanning or keying the price of grocery items, (2) bagging groceries, (3) tendering money, (4) waiting for a customer, and (5) miscellaneous (e.g., cleaning the checkstand). Using the time recorded on the videotape as a reference, epochs were tagged with a code to indicate which of the five tasks transpired during that epoch. For each cashier, the counts generated during each task were summed and divided by the number of epochs associated with the task. A complete within-subject, repeated-measures design was used in the analysis of variance to assess the significance of the main effects (recording site and task type) and interactions.

Results

Representative data obtained during an 8-hour work period from a cashier and from a clerk are displayed in Figure 2a and b, respectively. Bar heights indicate the total number of pulses generated during each 2-second epoch.

Perhaps the most noticeable difference between the two figures is shown in the third trace, which depicts leg motion (normally walking). It is evident from the left- and right-hand tracings that both jobs require near continuous hand movement. Mean counts/epoch recorded at each limb, during work and break periods, by job title (cashier and clerk) are plotted in Figure 3.

Several effects evident in Figure 3, all consistent with expectations, were verified by repeated analysis of variance. Two of these effects involved both groups of workers. First, activity levels recorded at both wrists were significantly higher during work periods than during break periods ($p = 0.0001$). Second, dominant (right) wrist activity exceeded nondominant (left) wrist activity ($p = 0.0001$). Notably, the effect of wrist on the recorded activity level was not significantly modified by the period (work or break) ($p = 0.2505$).

Predictions regarding differences between the patterns of activity exhibited by workers in the two job categories were supported. As indicated in Figure 3, wrist activity levels were significantly higher among cashiers than clerks during work periods ($p = 0.0001$). Conversely, activity levels recorded at the ankle were significantly higher among clerks than cashiers during work periods ($p = 0.0005$). Although there appear to be slight differences in wrist and ankle activity between cashiers and clerks during break periods, these differences were not statistically significant ($p > 0.10$).

Mean activity counts/epoch associated with different cashier tasks are displayed in Figure 4. As shown, activity levels recorded from the ankle were lower than those recorded from the wrists, and ankle activity did not vary widely in response to changes in task type. Consequently, data recorded from the ankle were excluded from statistical analyses of task influences on activity.

It can be seen in Figure 4 that dominant (right) wrist activity was higher than nondominant (left) wrist activity for all tasks. The effect of wrist on the recorded activity level was highly significant ($p = 0.0001$). This effect was not modified significantly by the task variable ($p = 0.10$). Rather, an identical pattern of task-related activity differences is apparent for the two wrists. Analysis of variance also confirmed that the main effect of task type was significant ($p = 0.0001$). *Post hoc* comparisons [Tukey's honest significant difference (HSD) test] indicated that wrist activity was significantly higher during scanning and bagging periods.[10] Tendering money and miscellaneous actions were associated with intermediate levels of

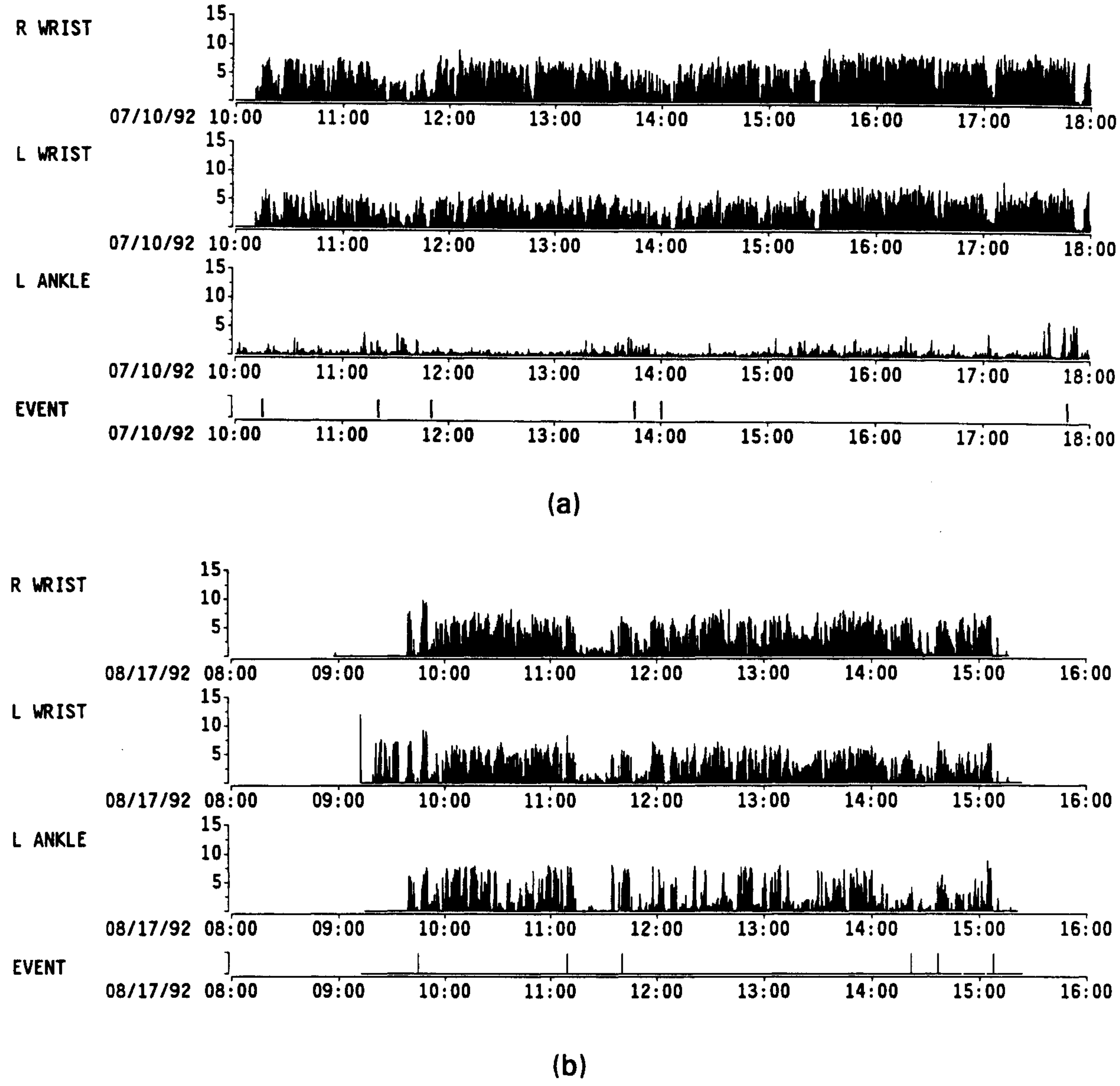

FIGURE 2. Activity data obtained from (a) a cashier and (b) a clerk over an 8-hour period.

wrist activity, whereas waiting for customers was associated with the lowest wrist activity levels (Table 1).

Discussion

For over a decade, activity monitors have been successfully used to monitor gross changes in physical activity, such as those associated with sleep/wake cycles, etc.[7,11] This technique has not as yet, however, been used to measure exposure to manual activities implicated in the development of upper extremity musculoskeletal disorders. Accordingly, this study employed activity monitoring to quantify variations in hand/wrist activity among retail food workers employed in different job tasks. Variations in work activity as indicated by the recorded data were consistent with predictions based on observations of the job tasks. For both cashiers and general merchandise clerks, recorded activity levels were significantly higher (1) for the dominant hand compared with the nondominant hand, and (2) during work periods than during break periods. During work periods, wrist activity was significantly higher among cashiers than general merchandise clerks, reflecting the greater use of the upper limbs in cashier work. By contrast, clerks are required to do more walking than cashiers, and this was reflected in the data recorded from workers' ankles. In addition, variations in the types of tasks performed by cashiers elicited significant variations in recorded activity levels.

Although the activity differences seen here would be discernible through more traditional procedures (in which activities are coded and movements are counted by human observers), those procedures entail more time and effort and may yield less precise data, especially if work activities are sampled rather than continuously monitored. In fact, traditional observational techniques may be insufficiently sensitive for detecting

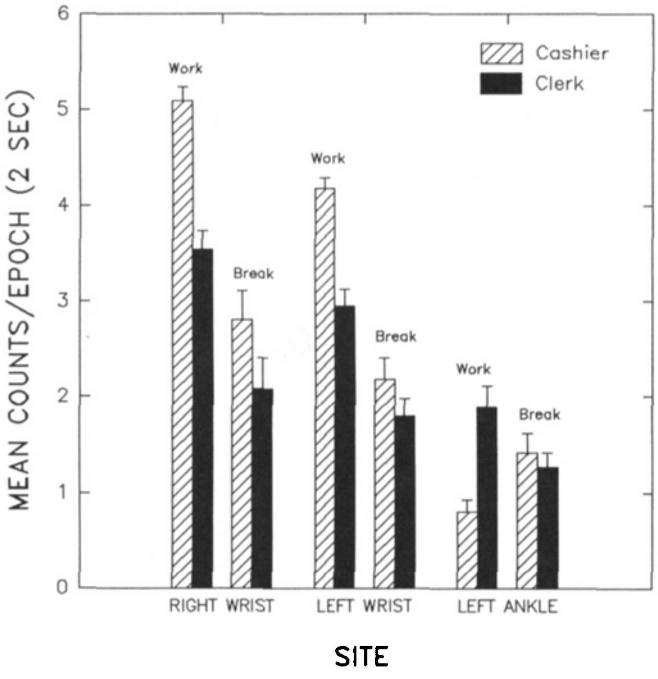

FIGURE 3. Cashier versus general merchandise clerk activity comparison.

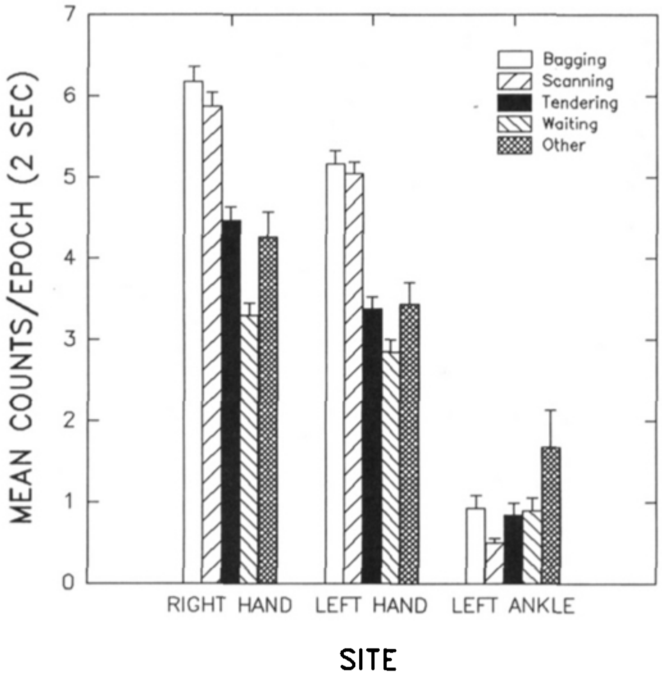

FIGURE 4. Cashier activity comparison by work task.

subtle activity differences which may nevertheless influence musculoskeletal injury risk. Certainly some of the effects detected by the activity monitors in this study would have been difficult, if not impossible, to detect by human observers. For example, scanning is generally considered a two-handed task; however, the recorded data indicate that in actuality the hands are not equally active. An attempt to quantify right:left hand activity ratios through observation would have required inordinate amounts of time and effort. Moreover, attempts to observe workers during break periods would have been intrusive and hence impractical. The technique used in this survey is not subject to these kinds of limitations. On the contrary, the activity monitors were well accepted by the participants in our study. They did not appear to influence the activities or movements of the workers wearing the monitors, and appear especially well suited for studies requiring long periods of continuous monitoring.

Despite the advantages provided by activity monitors over observational methods for quantifying manual activity, limitations in the approach remain. One disadvantage is that activity monitors are sensitive to all wrist movements, regardless of how the motion was produced. For example, pulses can be generated by involuntary accelerations of the wrist generated while walking, as well as by voluntary accelerations of the wrist during work activities. Since unintentional arm movements often produce accelerations lower in magnitude than accelerations associated with intentional arm movements, providing additional (higher) threshold settings could help to eliminate this problem. Newer designs that incorporate a low power A/D converter in place of the comparator will also allow the magnitude of the signal to be recorded in the unit's memory. Another limitation is that activity monitors are not sensitive to finger, hand, or wrist posture, or to forces produced by the hand during the movement. Hence, in most cases observational data describing the qualitative aspects of manual work activities are needed to supplement the quantitative activity data. For example, limb postures can be observed and coded on a periodic basis using a sampling scheme. Observational data are also needed to link periods of high activity with specific work tasks. By combining sampled data with continuously recorded activity data, the researcher should be able to derive a fairly comprehensive exposure index for workers performing different jobs. It is our hope that this approach will facilitate future epidemiological studies of the relationship between

TABLE 1. Results of Tukey's HSD Test

Hand	Mean (Bag)	Mean (Scan)	Mean (Tender)	Mean (Misc)	Mean (Wait)
Right*	6.18^{A}	5.87^{A}	4.46^{B}	4.26^{B}	3.29^{C}
Left**	5.16^{a}	5.04^{a}	3.36^{b}	3.43^{b}	2.85^{c}

Means with the same letter are not statistically different.
*Tukey's HSD = 0.49.
**Tukey's HSD = 0.45.

work activities and the development of upper extremity musculoskeletal disorders.

Disclaimer

Mention of the name of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

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