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Quantification of Wrist Motions during Scanning

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A laboratory study was performed to help assess the risk of cumulative trauma disorders (CTDs) associated with the use of scanners in the grocery store environment. In this study experienced and inexperienced cashiers scanned a set of 12 standard grocery items using 19 different combinations of scanners, scanner orientations, and check stands. The motion characteristics of both wrists in three-dimensional space were documented and used as dependent measures of performance. These motions were compared with wrist motion benchmarks of high- and low-risk wrist accelerations. It was found that, in general, scanning motions are of sufficient magnitude to contribute to CTDs of the wrist. It was also found that wrist motion characteristics were greatly influenced by the different combinations of scanners, scanner orientations, and check stand designs. It was concluded that the "front-style" check stand minimizes potentially injurious wrist motions because it permits the checker to split the scanning task between the two hands. The type of scanner and scanner orientation that minimized potentially injurious wrist motions was much more unique to the individual workstation condition. Additionally, it appears that scanners perceived by the checkers as needing fewer wrist deviations, such as those with slanted windows, also minimize wrist motions. The implications of these findings for the ergonomic design of the workplace are discussed.

INTRODUCTION

The reported incidence of cumulative trauma disorders (CTDs) has grown dramatically over the past several years. The Bureau of Labor Statistics reported that in 1981, 18% of occupational illnesses were attributable to cumulative trauma, whereas in 1991 this figure had grown to 62%. This trend also has surfaced in the grocery retail industry. For example, Buckle, Stubbs, and Baty (1986) reported that 56 percent of supermarket employees complained regularly of musculoskeletal discomfort. Canadian supermarket studies by Wallersteiner (1981), and Stoffman and Sterling (1983) as well as studies in the United States by Margolis and Kraus (1986) and Rosenstock, Barnhart, Longstreth, Mason, and Heyer (1985) have all reported increases in musculoskeletal complaints of checkout personnel. These studies indicated that CTD complaints have increased with the introduction of scanners into the checkout operation.

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Safety and Health (NIOSH) recently performed a health hazard evaluation of workers in supermarkets (Baron, Milliron, Habes, and Fidler, 1991; Orgel, Milliron, and Frederick, 1990) and found an increased risk of developing carpal tunnel syndrome (CTS) if the checker had worked at the job for 10 or more years or had worked more than 25 hours per week.

Risk Factors

Wrist posture, repetition, tendon force, and wrist acceleration are the four major contributors to CTDs. Wrist posture has frequently been cited as a risk factor for CTS and CTDs (Alexander and Pulat, 1985; Armstrong, 1983, 1986a, 1986b; Armstrong and Chaffin, 1979a, 1979b; Armstrong, Foulke, Joseph, and Goldstein, 1982), tenosynovitis, and De Quervain's disease (Armstrong, 1983). Few researchers have quantified "how much" wrist deviation exposes a worker to CTDs; however, the suggested association between wrist posture and CTDs has been explained biomechanically by Tichauer (1978) and Armstrong and Chaffin (1979b).

Repetition also has been cited as a risk factor by Silverstein and colleagues, (Silverstein et al., 1985; Silverstein, Fine, and Armstrong, 1986, 1987), who conducted two epidemiological studies. Unlike static wrist posture, repetition involves the dynamic components of angular velocity and acceleration, which could contribute to the risk for CTS and CTDs. Based on Newton's second law of motion, the extrinsic muscles in the forearm must exert a force proportional to the angular acceleration (rotational inertia) of the hand. Schoenmarklin and Marras (1993) developed a dynamic biomechanical model of the wrist joint that explained how angular acceleration of the wrist theoretically increases the resultant reaction force on the median nerve and flexor tendons, thereby increasing the risk of CTS and CTDs overall. Risk attributable to repetition also is influenced by factors such as recovery time and time between repetitions.

The frictional energy generated as a tendon is moved over adjacent surfaces also is hypothesized to be a major cause of CTDs (Moore, 1988; Moore, Wells, and Ranney, 1991; Tanaka and McGlothlin, 1989). The association between tendon force and incidence of CTDs can be explained by Armstrong and Chaffin's (1979b) static model of the wrist. The resultant tensile and shear reaction force on tendons increases linearly as tendon force increases. The resultant reaction force can theoretically contribute to deterioration and inflammation of the tendons. The Silverstein et al. (1986, 1987) studies also support force as a CTD risk factor.

Work situations that combine repetition and high forces increase the risk of CTDs dramatically. Silverstein et al. (1986, 1987) found a 14:1 odds ratio of high-repetition, high-force jobs to low-repetition, low-force jobs.

Marras and Schoenmarklin (1991, 1993) recently identified wrist acceleration as an additional risk factor. In that study, industrial workers performed jobs entailing highly dynamic and repetitive motions of the wrist; wrist range of motion, angular velocity, and angular acceleration were recorded from each plane of the wrist. The results indicated that although there were no statistically significant differences in wrist range of motion between the high- and low-risk groups, wrist velocities and accelerations were significantly greater in the high-risk group than in the low-risk group in every plane of the wrist. Flexion/extension acceleration was found to be the most robust indicator of CTD risk, with an odds ratio of 6:1. Mean wrist flexion/extension accelerations were 490 deg/s^2 in the low-risk jobs and increased to 820 deg/s^2 in the high-risk jobs. It is believed that wrist motions contain the essential elements of the wrist posture and repetition risk factors. The static (wrist posture) and dynamic (angular velocity and acceleration) components of tendon force also are contained within such a measure. The study concluded that these flexion/extension acceleration limits could be used as composite risk indicators of CTD risk for highly repetitive and highly dynamic jobs in which hand tools are not used.

Some might question the anatomic basis for acceleration as a risk factor, given that many of the prime movers of the wrist do not pass through the carpal tunnel. We believe that acceleration is an appropriate risk indicator, for at least two reasons. First, we have found (Marras and Schoenmarklin, 1991, 1993) that acceleration is a risk factor for CTDs in general, not specifically for CTS. Thus, for many CTDs it does not matter whether the tendons passing through the carpal tunnel experience tensile force. Second, because workers often assume pinch grips during scanning, we believe that increased tendon tension would be experienced by the secondary wrist movers that are also connected to the fingers. These tendons do pass through the carpal tunnel and, thus, would be expected to increase the risk of CTS when accelerating, as is the case during scanning.

Measures of Risk during Scanning

The scanning task in a checkout operation involves highly repetitive and dynamic actions of the hand and wrist. Traditional measures of risk do not apply to the scanning task. Wrist posture assessment is inappropriate because scanning is highly dynamic. It is currently infeasible to eliminate the need for the checker to handle the items that will be scanned. Thus, the repetition variable cannot be easily manipulated except through administrative controls. The risk factor of tendon force is also very difficult to assess or control in a scanning task that requires grasping various items. Thus, the only risk factor that can be assessed in this situation is wrist acceleration. Dynamic wrist motion assessment appears to be an appropriate risk measure, given that scanning is a highly dynamic task.

Objective

It is assumed that the workplace can be redesigned to mitigate the risk of CTDs. However, examination of various supermarket environments indicates that workers can be exposed to a variety of check stands, scanners, and scanner orientations (horizontal vs. vertical) in supermarkets. Therefore, the objective of this project was to use wrist motion analysis techniques to assess the CTD risk associated with the various combinations of these variables.

METHODS

Wrist accelerations were monitored using wrist goniometers developed at the Ohio State University Biodynamics Laboratory. Because not all of the scanners could be used in all the orientations or check stands, the statistical design was unbalanced. Only appropriate comparisons were made in the statistical analyses.

Subjects

The subject pool consisted of 8 college-age men (ages 18–26), 4 of whom had two or more years' experience scanning groceries as checkers (experienced). The remaining 4 subjects had no previous experience scanning groceries (inexperienced). Both experienced and inexperienced subjects were tested under all conditions so that the influences of both learning effects and familiarity with a particular workstation could be controlled. A summary of the subjects' gross anthropometry is shown in Table 1.

Experimental Design

The three independent variables believed to affect wrist motions consisted of scanner type, scanner orientation, and check stand type. These variables were chosen because they represented most supermarket workplace conditions. Four different scanners were used to represent common scanners. Scanner A was a hybrid, medium-performance scanner with enhanced decode capability. Scanner B was a high-performance vertical scanner with standard decode capability. Scanner C was a hybrid, high-performance scanner with standard decode capability. Scanner D was a high-performance scanner with enhanced decode capability. Figure 1 portrays the layout of each of the five check stands used in this study: front (FRT), side (SID), over the end (OTE), European (EUR), and right hand takeaway (RHT). The European check stand is designed so that the checker is seated, whereas for all other check stands, the checker is standing. Scanners are oriented either

TABLE 1

Subject Anthropometry

Subject	*Age*	*Stature (cm)*	*Wrist Width (mm)*	*Wrist Thickness (mm)*	*Hand Length (mm)*
			Experienced Subjects		
BC	22.0	173.6	56.0	38.8	187.0
CB	20.0	183.1	52.0	33.0	192.0
DB	22.0	174.1	49.0	35.0	192.0
TS	18.0	180.5	62.0	40.0	155.0
Mean	20.5	177.8	54.8	36.7	181.5
SD	1.7	4.1	4.9	2.8	15.8
			Inexperienced Subjects		
DN	21.0	179.0	51.0	31.0	188.0
EB	22.0	182.1	55.0	40.0	199.0
GM	26.0	197.3	64.0	39.0	213.0
JL	23.0	172.5	51.0	40.0	174.0
Mean	23.0	182.7	55.3	37.5	193.5
SD	1.9	9.1	5.3	3.8	14.3

horizontally or vertically within a check stand. A scanner orientation is horizontal when the scanner face is flush with the check stand work surface. Orientation is considered vertical when the scanner face is oriented perpendicular (vertical) to the checkstand work surface. Some scanners can be used in a combination of orientations, whereas others are dedicated as either horizontal or vertical. Figure 2 shows the orientation of the scanners relative to the check stand configuration and scanner type used in this experiment. These 19 different combinations of check stand, scanner, and scanner orientation constituted the experimental conditions in this study.

A blocking variable consisting of subject

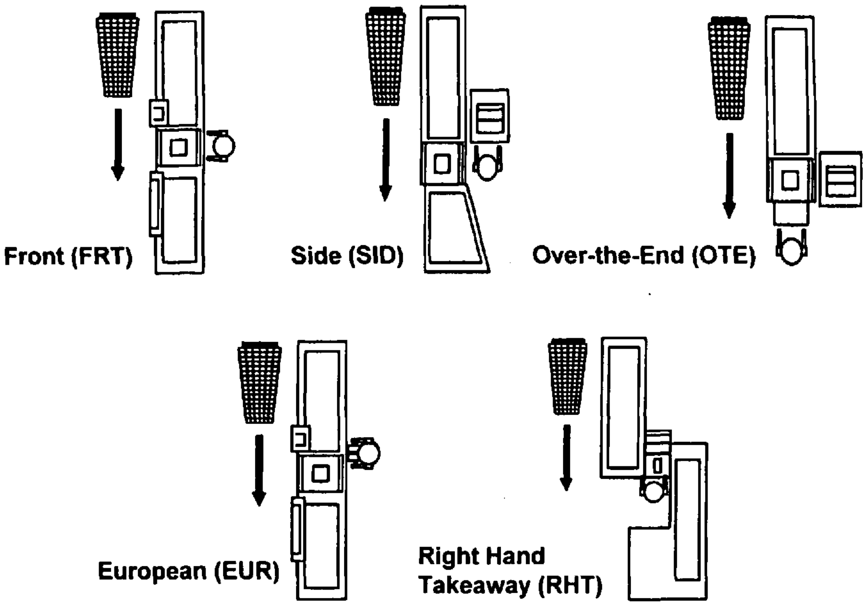

Figure 1. *Check stands used in experiment.*

	SCANNER			
CHECKSTAND	A	B	C	D
Right- Hand-Takeaway (RHT)		V	H,V	H
Over-the-End (OTE)			H,V	H
Front (FRT)		V	H,V	H
Side (SID)			H,V	H
European (EUR)	H,V	V	H,V	

H= Horizontal
V= Vertical

Figure 2. *Orientations of scanners used in experimental conditions.*

experience was also included in this study. The experiment was a repeated measures design because each of the eight subjects performed the scanning task on each of the checkstand combinations. Finally, the design was unbalanced because not all scanners were capable of being used in both scanner orientations.

Each of the 12 different grocery items used in this experiment was from one of four different categories: canned goods, boxed goods, bottled goods, and flexible goods. For each category, three different sizes (small, medium, and large) were used. As a group, these grocery items represent approximately 76% of all the grocery items normally scanned by grocery store checkers each day (M. Hoffman, personal communication, 1988).

Finally, the three dependent measures in this study consisted of mean wrist angular acceleration in the flexion/extension, radial/ulnar, and supination/pronation planes of the wrist. These mean accelerations were defined over the period during which the subject's hand was in contact with each item. Thus, the time between scanning operations was not used to compute mean acceleration. This processing of the "active scanning" period was done so that the data would be compatible with and comparable to that from the industrial risk study (Marras and Schoenmarklin, 1991, 1993).

Apparatus

Data were collected from the subject's forearm and wrist via three goniometers: one measuring radial/ulnar movements, one measuring flexion/extension movements, and one measuring pronation/supination movements. Collectively, these goniometers were lightweight (less than 0.05 Kg) and offered very little resistance to motion. The radial/ulnar and flexion/extension monitors consisted of two segments of thin metal connected by a rotary potentiometer. This potentiometer measured the angle between the two metal segments. The pronation/supination monitor consisted of a rod attached to a bracket fixed to the forearm with tape. The proximal end of this rod was fixed to a Velcro cuff. This rod remained parallel to the forearm during rotation, but a potentiometer located on the distal end of the rod rotated with respect to the rod as the forearm rotated. This potentiometer measured the angular displacement of the forearm.

Additionally, two manually activated switches were utilized as timing markers so that mean acceleration could be defined. One timing marker was activated just prior to the time the subject first grasped the grocery item, and the second timing marker was activated when the subject released that grocery item. All data obtained from the goniometers, timing markers, and scanning signal were fed into an A/D board and in turn fed into a Compaq 386 computer. Data were stored on a 44-megabyte Bernoulli removable hard disk. The data were compiled into a custom-designed data collection program, which combined input from the nine data channels of the A/D board with temporal data at the chosen data collection frequency (300 Hz).

Analyses

Laplace transformations were utilized to simultaneously solve the equations predicting position, velocity, and acceleration from the raw voltage signal collected from the goniometers. When three-dimensional wrist positions calculated by this procedure were compared with positions calculated by standard video-based techniques, our estimates were within 3% of the video-based estimates in the flexion/extension and radial/ulnar planes and within 4% of the estimates in the supination/pronation plane. It is likely that the goniometer-based predictions are more accurate than the video-based predictions. The details of this analysis technique have been reported by Marras and Schoenmarklin (1991). A computer program computed the mean, minimum, and maximum values and standard deviations for position, velocity, and acceleration in all three planes for both hands.

Statistical analyses were performed using multivariate analysis of variance (MANOVA) to evaluate the differences among all wrist motions in all planes considered as a collective set. When statistical significances were found, analyses of variance (ANOVAs) were performed to evaluate differences among wrist motion parameters in each plane individually. Finally, specific post hoc tests were performed to further delineate the specific nature of the differences found by the ANOVAs.

Procedure

A training session was permitted to minimize learning effects. Inexperienced subjects were permitted a 45-min practice session so that they could become familiar with the location of the Universal Product Codes on the various grocery items as well as with scanning. Both the experienced and inexperienced subjects were permitted at least a 5-min familiarity period with each check stand-scanner orientation-scanner condition. Experimental data were collected only when the subjects felt comfortable with each condition.

The monitor measuring radial/ulnar movement was positioned at the approximate center of the wrist width and aligned with the third metacarpal distally and the lateral epicondyle proximally. The monitor measuring flexion/extension was positioned at the approximate center of wrist thickness on the ulnar side slightly proximal to the styloid process, aligned with the ulnar aspect of the fifth metacarpal distally and the tip of the olecranon process proximally. The centers of wrist width and thickness are considered good approximations of the joints' center of rotation (Brumfield and Champoux, 1984; Webb Associates, 1978). The pronation/supination monitor was aligned with the wrist monitor measuring flexion/extension movements, with its distal end located approximately 1.5 to 2.0 inches (3.8–5.1 cm) proximal of the styloid process of the ulna and the proximal end secured to a Velcro cuff situated 1 inch (1.5 cm) distal to the olecranon process. After the monitors were applied and calibrated, the experiment began.

The subject scanned 8 grocery items during each trial. The grocery items were placed on the check stand's conveyer belt in a random orientation but at a distance tantamount to a 2-s time gap. Surrogate items (grocery items other than the 12 items of interest) were alternated with the grocery items of interest. These surrogate items were necessary so that the time a subject handled a particular item of interest could be documented. Because it is possible to hold two items simultaneously (one in each hand), it would be difficult to document the pick-up and set-down times for each item of interest without alternating the items of interest with surrogate items. Data were collected and stored for nine trials such that each grocery item of interest was read by the scanner three times in each experimental condition. Finally, a video camera was used to film the subjects as they performed the experiment.

RESULTS AND DISCUSSION

Statistical Significance

A summary of the statistically significant differences among the various experimental conditions is shown in Table 2. This table shows which wrist accelerations in each hand are affected by the workstation variables (scanner type, scanner orientation, and check stand) and combinations of these factors. The columns within these tables show the significance level of the MANOVAs as well as the univariate ANOVAs for each wrist motion variable (at a significance level of 0.05). Additional results have been reported elsewhere (Food Marketing Institute Report, 1990).

One of the more interesting findings in this

TABLE 2

Summary of MANOVA and ANOVA Significance

		ANOVAs Average Acceleration					
		Left Hand			*Right Hand*		
Experimental Variables	*MANOVA*	*F/E*	*R/U*	*P/S*	*F/E*	*R/U*	*P/S*
Experience	—	—	—	—	—	—	—
Horizontal Scanners	0.0001	0.0001	0.0001	0.0001	—	—	0.05
Vertical Scanners	<0.0001	0.0001	0.1	—	0.0001	0.0001	0.0001
Scanner	0.0001	—	—	—	0.0008	0.0001	—
Checkstand	<0.0001	0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Checkstand × Horizontal Scanners	0.0001	0.0054	0.0001	0.0626	0.0001	0.0001	0.0001
Checkstand × Vertical Scanners	0.0001	—	—	—	0.0001	0.0001	0.0001
Scanner × Checkstand	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Experience × Checkstand	<0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Experience × Scanner	0.0001	—	0.0008	0.0001	0.0047	0.0001	0.0857
Experience × Horizontal Scanners	0.0001	0.0001	0.0001	0.0152	0.0001	0.0001	0.0037
Experience × Vertical Scanners	<0.0001	—	0.0001	0.0001	0.0001	—	0.0001
Scanner Orientation × Scanner × Checkstand	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note. F/E = flexion/extension; R/U = radial/ulnar; P/S = pronation/supination.

study was that subject experience, by itself, did not significantly influence wrist acceleration characteristics. This means one cannot expect that merely selecting experienced or inexperienced workers will reduce the incidence of CTDs. More important, these results show that the wrist accelerations of both experienced and inexperienced workers can be influenced via engineering of the workstation factors.

Trends

As shown in Table 2, the Scanner × Scanner Orientation × Check Stand interaction was highly significant for all wrist motions. The combined effect of these three workstation variables was the overriding factor that influenced wrist motions during scanning. Two-way and three-way effects will be discussed following the main effects.

Checkstands. The main effect of check stand design for both radial/ulnar and flexion/extension acceleration is shown in Figure 3. No one check stand resulted in wrist accelerations below the low-risk benchmark for both acceleration planes. However, when considering the flexion/extension and radial/ulnar planes of the wrist collectively, the European and front checkstands yielded the lowest acceleration levels.

Scanners and scanner orientation. The flexion/extension and radial/ulnar wrist acceleration results for the horizontally oriented scanners indicate that both Scanner C and Scanner D performed similarly in this orientation. Both wrist plane accelerations are fairly close to the low-risk benchmark. The only deviation

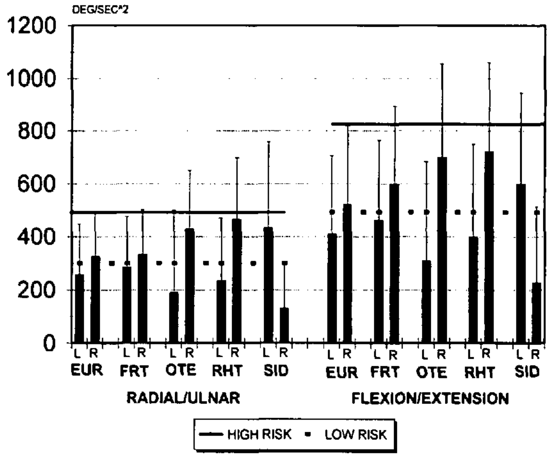

Figure 3. *Wrist acceleration as a function of check stand.*

appeared to be in the left wrist in the radial/ulnar plane. In this case, Scanner C yielded accelerations approaching the high-risk benchmark.

The flexion/extension and radial/ulnar accelerations for the vertically oriented scanners are near the low-risk benchmark for Scanner B, whereas Scanner C yields accelerations well above the low-risk benchmark.

The effects of scanner orientation on flexion/extension and radial/ulnar acceleration indicate that although both orientations yield accelerations above the low-risk benchmark, the horizontal scanner requires slightly less wrist acceleration in both the flexion/extension and radial/ulnar planes.

Scanner × *Check Stand interation.* The effects of using the horizontal scanners in the various check stand designs on flexion/extension accelerations are shown for the right and left wrists in Figure 4. This figure shows that, under most conditions, Scanner C resulted in greater accelerations for the left wrist, but Scanner D resulted in greater accelerations in the right wrist for the RHT and OTE checkstands. Generally, the right wrist accelerations were greater except for the SID checkstand condition. Note that if one considers the greater of the two hand accelerations under all conditions, at least one hand approaches an acceleration level of at least 590 deg/s^2. The OTE and FRT check stands appeared to be the conditions under which the maximum acceleration (between the two hands) was minimized. However, different scanners resulted in the lower of the accelerations in each of these conditions.

The acceleration effects relative to the high- and low-risk benchmarks in the radial/ulnar plane for both hands exhibited patterns similar to those for flexion/extension acceleration. However, observed accelerations were greater in the left hand than in the right. Focusing then on the left hand, the FRT and OTE check stands minimized wrist acceleration of this hand.

The flexion/extension and radial/ulnar acceleration characteristics for the right hand also were studied to find the effect of the vertical scanners in the various check stands. Table 2 indicates that the left hand did not exhibit any statistically significant differences in this

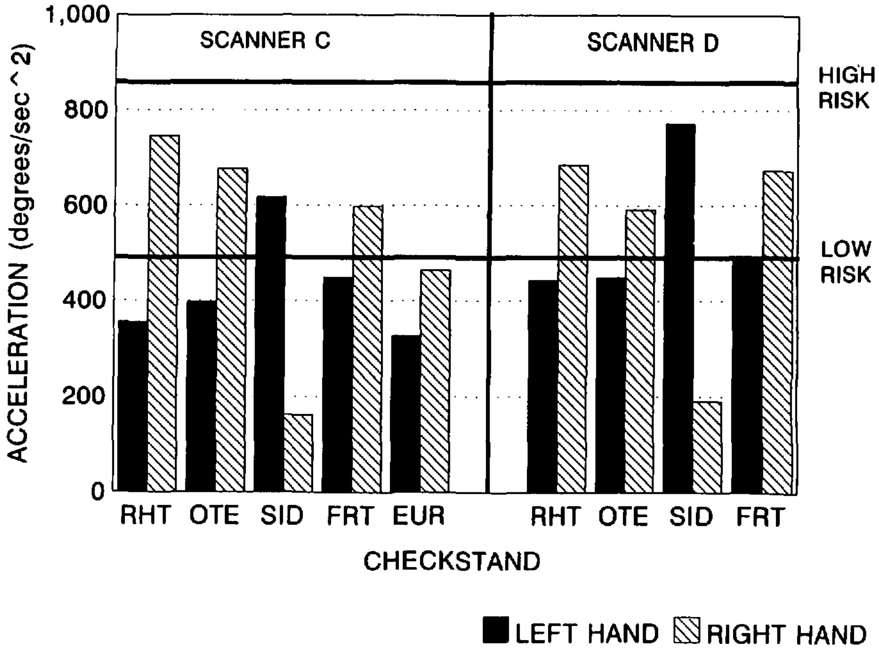

Figure 4. *Scanner* × *Checkstand interaction for flexion/extension acceleration.*

interaction. The FRT checkstand orientation was found to minimize the maximum acceleration in both planes of wrist motion. Scanner C always produced greater accelerations than Scanner B in both wrist planes.

Scanner Orientation × *Checkstand interaction.* A comparison of the results for the two hand accelerations shows a significant trade-off in acceleration of the right and left hands when using the RHT, OTE, and SID check stands. Accelerations using the RHT and OTE were much higher for the right hand than for the left. A large difference between the vertical and horizontal scanners occurred in the SID check stand condition, where the horizontal orientation of the scanner significantly reduced right flexion/extension acceleration. Scanner orientation did not make much difference with the other check stands. Among the various checkstands, the FRT and EUR checkstands minimized the maximum acceleration of the wrist in the flexion/extension planes. The radial/ulnar wrist accelerations as a function of the scanner orientation and check stand were similar to the flexion/extension results described here. The FRT and EUR checkstands minimized the maximum wrist accelerations in both hands.

Scanner × *Scanner Orientation* × *Check Stand interaction.* Figure 5 shows means for flexion/extension average acceleration for the unique combinations of scanner, scanner orientation, checker orientation, and check stand on the entire scanning time period for all items. This figure shows right and left wrist accelerations compared with the low- and high-risk benchmarks for flexion/extension wrist accelerations reported by Marras and Schoenmarklin (1991). It should be emphasized that these high- and low-risk benchmarks represent the 50th percentile high- and low-risk wrist accelerations observed in the Marras and Schoenmarklin study. Thus, these benchmarks should not be considered as absolute limits of high- and low-risk motions. Instead, they should be thought of in terms of a probabilistic continuum around each benchmark. For example, if the observed wrist

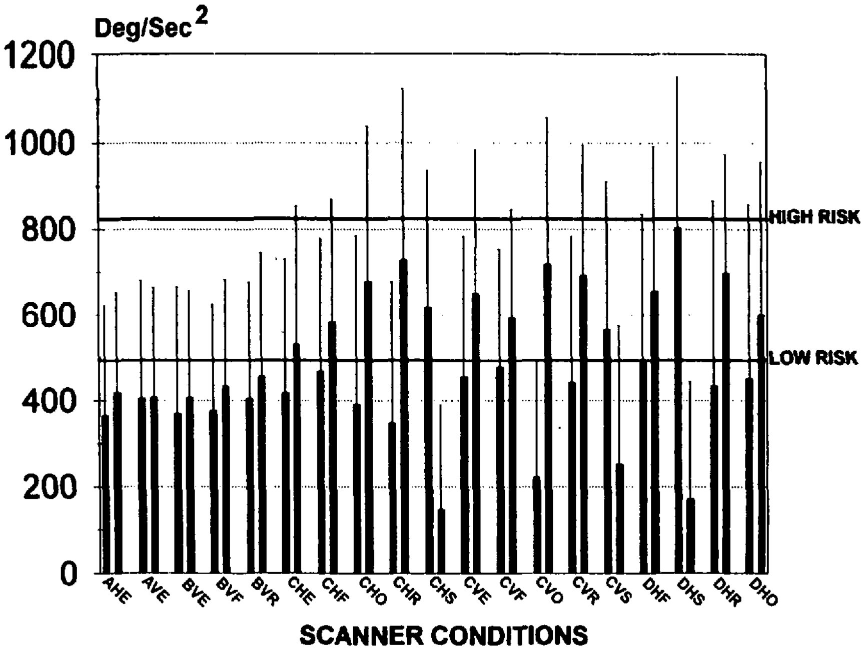

Figure 5. *Wrist acceleration by condition for flexion/extension acceleration (mean and standard deviation). First letter = scanner, second letter = scanner orientation, third letter = check stand (see Figure 2). Each condition displays left hand followed by right hand.*

acceleration is slightly below the high-risk benchmark, this wrist acceleration is not necessarily risk free. Wrist accelerations should be compared relative to one another and only considered risk free if the accelerations are well below the low-risk benchmark.

Figure 5 underpins concern about the potential dangers of flexion/extension accelerations that are imposed on the wrist during scanning. This figure indicates that 14 of the 19 workstation combinations exceeded the low-risk benchmark. On the other hand, it is encouraging to note that the first five workstation combinations lie below the low-risk benchmark. This indicates that one may be able to control CTD risk through the improved workstation design.

Several criteria should be considered when examining Figure 5. First, one should try to pinpoint the conditions where the acceleration is low in both wrists. The goal is to minimize total acceleration in each wrist. If one hand exhibits extremely high acceleration and the other exhibits extremely low acceleration, then one should judge the condition based on the high wrist acceleration (worst case). Second, one should keep in mind that these figures show only wrist accelerations. However, the effect of a particular condition on other parts of the body must be taken into account. For example, it is suspected that some of the first five conditions, which are least risky for the wrist, might increase the risk of shoulder problems.

Based on the information presented in Figure 5, the best conditions appear to be the first five conditions. Note that there are two different scanners, two different orientations, and three different check stands represented in these five workstations. This again points to the need to consider specific workstation combinations in the assessment of the experimental results.

Figure 6 shows the radial/ulnar wrist accelerations for the same time period. This figure indicates that, in general, the same conditions that were preferable in the flexion/extension plane were preferable in the radial/ulnar plane. The RHT condition was the worst in both planes.

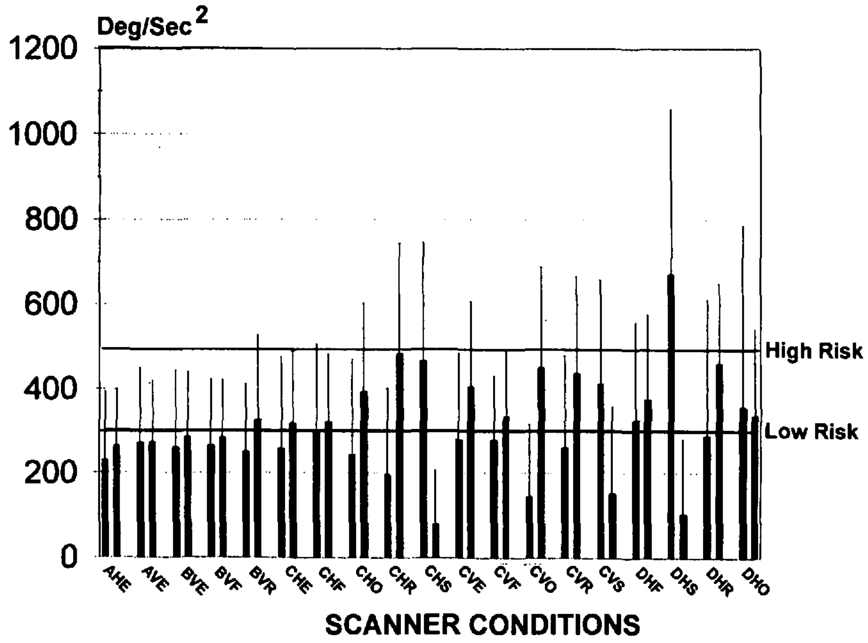

Figure 6. *Wrist acceleration by condition for radial/ulnar acceleration (mean and standard deviation). First letter = scanner, second letter = scanner orientation, third letter = check stand (see Figure 2). Each condition displays left hand followed by right hand.*

Wrist Accelerations as a Function of Product

After viewing the three-way interaction of scanner, scanner orientation, and check stand for each item scanned, we found that there is not a single situation where the scanning of an item resulted in wrist accelerations below the low-risk benchmark for all workstation conditions. Thus, any item can result in a high-risk acceleration. The wrist accelerations cannot be lowered to a safe level simply through package redesign.

CONCLUSION

It is extremely difficult to determine which combination of workstation factors should be used to minimize the risk of CTD. This is because many confounding factors are associated with such an evaluation, and some risk factors (such as repetition or force), because of study assumptions, were not observed in this experiment. It also must be remembered that this was a laboratory study and that these results need to be verified in the field.

Even though the European check stand resulted in the lowest wrist accelerations, it is not recommended as an ideal check stand. When checkers are scanning while seated, as is common with this check stand, severe back loading, as well as awkward shoulder postures, would be expected. Therefore, excluding this check stand from consideration, we can compare wrist accelerations in both wrist planes as a function of the workstations to conclude the following:

1. Workstations that incorporated the FRT checkstand generally resulted in some of the lowest-risk wrist accelerations. This was true for both Scanner B, a vertical scanner, and Scanner C in either orientation. These workstation combinations appeared to be the best. However, Scanner D in the horizontal orientation did not show this same benefit.
2. Workstations using either Scanner D or Scanner C in the horizontal orientation in conjunction with the SID workstations resulted in the greatest risk. These workstation combinations should be avoided.
3. Risk associated with the RHT checkstand varied greatly according to the scanner and scanner orientation. This workstation represented a rather low risk condition when it was incorporated with Scanner B in a vertical orientation. The risk was rather high with Scanner C in the horizontal orientation. A somewhat lesser, yet still significant, risk would be expected with Scanner C in the vertical orientation or Scanner D in the horizontal orientation.
4. The risk associated with the OTE checkstand also varied according to condition. It appeared to represent significant risk when incorporated with scanners in the vertical orientation and a more moderate risk when incorporated with Scanner D or Scanner C in the horizontal orientation.

Workstation Hypotheses

These results lead to two models of how workers behave biomechanically during scanning. First, the design of the check stand dictates whether a worker uses one or both hands to scan items. The FRT checkstand was generally preferable because it permitted the work to be shared by both hands. In the SID or RHT workstations, only one hand was involved in the scan, so the subjects increased their wrist accelerations to maintain productivity.

Second, we have observed that dynamic wrist motion characteristics are influenced by the scanner design, even though the scanner decoding effectiveness is the same in different designs. We believe that subjects create a mental model of how the scanner beams emanate from the scanner. It has been observed that most subjects deviate the wrist so that the UPC code is parallel to the scanner window. This would explain why Scanner B often outperformed the other scanners, even under identical check stand and scanner orientation conditions. Scanner B's window is not truly vertical. Instead, it is tilted upward at a slight angle so that the checker perceives that there is no need to deviate the wrist in order to place the UPC code perpendicular to the window. In actuality, however, the optics of this scanner are designed vertically, as with the other vertical scanner.

Because the checker's perceptions appear to greatly influence the amount of wrist deviation associated with scanning, future scanners should be designed to have multiple scan beams and windows. Consequently, it is expected that the checker will perceive no need to deviate the wrist, regardless of the position of the item's

UPC code. Thus, placing multiple windows on the scanner at various angles may affect the checker's perceptions such that the checker does not feel the need to deviate or sweep the wrist. However, further research must be performed to test this hypothesis.

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