Prevalence of Carpal Tunnel Syndrome and Other Work-Related Musculoskeletal Problems in Cardiac Sonographers

Heidi E. Vanderpool, MPT
Elizabeth A. Friis, MSME
Barbara S. Smith, PhD, PT
Kenneth L. Harms, BA

Cardiac sonographers at a regional medical center have experienced carpal tunnel syndrome symptoms and other work-related musculoskeletal injuries. The nationwide incidence of these problems was not known. A questionnaire pertaining to possible causes of work-related injuries was developed and distributed to 225 cardiac sonographers. A 47% response rate was achieved with 72% female respondents. Eighty-six percent reported one or more physical symptoms. Only 3% of respondents had been diagnosed with carpal tunnel syndrome. Posture correlated significantly with other work-related musculoskeletal injuries. High-pressure hand grip correlated significantly with carpal tunnel syndrome symptoms. No other strong relations with physical symptoms were found. The contribution of specific factors to musculoskeletal problems experienced by cardiac sonographers was difficult to determine.

Musculoskeletal disorders are now the leading cause of reported occupational illness in the nation.[1] Millions of workers are at risk of injuries from repeated trauma. Application of repetitive stress to any tissue may cause pain, loss of function and, in some cases, permanent disability. Many of these disorders have been brought about by technological advancements in the work environment.

Diagnostic medical ultrasound (sonography) is a relatively new technology in medicine that was first recognized by the American Medical Association in 1974, but had been utilized in the clinical setting 10 years before its official recognition. Early sonography systems were primitive and cumbersome; however, recognition of the tremendous diagnostic capabilities of sonography led to development of streamlined equipment and efficient procedures such as cardiac ultrasound. This new technology has resulted in increases in both the number of sonograms requested and the duration of each patient session.[2] Some researchers indicate that this new work environment may be potentially hazardous to sonographers even though the diagnostic ultrasound waves are safe for patients and sonographers.[3,4] The health hazards posed to sonographers are carpal tunnel syndrome and other work-related musculoskeletal injuries.

The medical literature provides sparse information on the frequency of carpal tunnel syndrome (CTS) and other work-related musculoskeletal injuries among cardiac sonographers. CTS is the compression neuropathy

From the Department of Physical Therapy, The Wichita State University (Ms Vanderpool, Dr Smith), the Orthopaedic Research Institute, Inc, (Ms Friis), and the St Francis Regional Medical Center (Mr Harms), Wichita, Kans.

Address correspondence to: Elizabeth A. Friis, Orthopaedic Research Institute, Inc, 929 N. St. Francis, Wichita, KS 67214.

0096-1736/93/3506-0604$03.00/0

of the median nerve at the wrist, which results in symptoms of burning pain, numbness, and tingling in the thumb, index and long fingers, and the lateral half of the palm. Progressive atrophy of the thenar muscles, with or without pain and numbness in the median nerve distribution in the hand, also may be caused by compression of the median nerve beneath the transverse carpal ligament.[2] Other work-related musculoskeletal injuries include those of the neck and back caused by overload of a particular muscle group(s) from repeated use or by the maintenance of inefficient postures which result in pain.

In 1985, Craig[3] identified health hazards associated with long-term activities as a sonographer. Among the primary problems covered were the increased risk for sonographers to develop CTS and joint and muscular damage, as well as latent possibilities of developing eye strain. Craig later performed an update of occupational hazards associated with sonography.[4] Improvement in equipment design and encouraging sonographers to scan while seated eliminated many complaints of the lower extremity pain. However, even with these improvements, eye strain and neck, back, shoulder, and upper extremity pain were still common in the sonographer's workplace.[4]

Various occupational health groups, universities and medical centers have conducted studies that examine the relation between musculoskeletal injuries and occupational factors.[5–16] These studies address generic aspects of repetitive motion in work-related disorders and therefore can be applied to sonographers even though they do not specifically address cardiac sonography. As in other occupations, cardiac sonography requires static and dynamic loading of the musculature of the neck, back, shoulders and upper extremity. In cardiac sonography, static or sustained isometric contraction of the neck, back, shoulder, and upper extremity are necessary to support and fix the arm in a position to hold the transducer against the patient. Conversely, dynamic or repetitive movements of the shoulder, forearm, wrist, hand, and fingers are needed to manipulate the transducer around the patient's left chest area and adjust the monitor. Literature suggests that for various occupations, a person who maintains an efficient posture and actions and whose work load includes a recovery phase can perform and sustain movements without injury.[17] However, many combined factors may contribute to musculoskeletal injuries of the individual. These factors include (1) age, (2) gender, (3) inefficient posture, (4) frequent and forceful repetitive movements, (5) extreme joint position, (6) ergonomic design, (7) equipment and task design, (8) duration and intensity of work without rest, (9) inactivity, and (10) health status.[17–19]

The symptoms manifested in CTS and other musculoskeletal injuries can impede the cardiac sonographer's performance and ability, infringe upon his or her lifestyle, and, in some cases, lead to workers' compensation suits. The incidence of CTS and related neck and back pains can be reduced or eliminated by ergonomic design of the workplace, equipment designs, workload, and intensity with a recovery phase and procedural techniques with joints in optimum position.[8,17–24] Work load and intensity for the cardiac sonographer may be related to the number of years worked, average days per week worked, average hours per day worked, average number of cardiac procedures done per day, and the average length of each patient examination.

In this study the incidence of work-related disorders in the cardiac sonographer population was examined through a survey distributed to randomly selected members of a professional sonographer society. The purposes of this study were to (1) ascertain whether there is a need for modifications of equipment and/or work environment of cardiac sonographers, (2) reveal how CTS symptoms and other work-related musculoskeletal injuries (combined physical symptoms) relate to work load and procedural techniques of a cardiac sonographers, (3) help define recommended work load and procedural techniques, and (4) determine how other factors, such as age, gender, and physical activity, contribute to the development of cardiac sonographers discomfort and/or exacerbate an existing problem.

Methods

Survey Distribution and Formulation

A pilot survey was developed based on the literature and reports of problems experienced by local cardiac sonographers. Twenty-five pilot surveys were distributed; no major survey problems were found. Two hundred final surveys were distributed. Participants were randomly selected from the national membership directory of the American Registry of Diagnostic Medical Sonographers.

The survey consisted of questions pertaining to age, gender, work load and intensity, technique of a cardiac ultrasound procedure, general medical history, physical activity, CTS, and other work-related musculoskeletal injuries. Questions pertaining to work load and intensity included the number of years worked, average days per week worked, average hours per day worked, average number of cardiac ultrasound procedures done, and the length of each patient's examination. Cardiac ultrasound procedure technique identification consisted of questions pertaining to percentages of examination time using specific wrist motions, hand grip pressures, working positions, and postures maintained during a procedure. Physical activity was defined as the number of days per week the respondent exercised 20 minutes or longer.

CTS symptoms included the following: (1) tingling in the thumb and/or index and middle fingers, (2) numbness in the thumb and/or index and middle fingers, (3) shooting sensations in the thumb and/or index and middle fingers, (4) burning pain in the thumb and/or index and middle fingers while working, (5) numbness in hands upon awakening, (6) pain at night in wrist and/or hand, (7) changes in muscle bulk of the palm of hand, and (8) clumsy fingers.

Other work-related musculoskeletal injuries listed the following symptoms: (1) pain in neck and/or back, (2) tingling and/or numbness in extremity(s), (3) shooting sensations into the extremity(s), (4) pain is constant, (5) pain is intermittent, (6) pain at night in neck and/or back, (7) pain at the end of the day, (8) pain in standing or walking, (9) pain in sitting, (10) weakness with pain, (11) weakness without pain, (12) restriction of motion in the neck and/or back, and (13) difficulty performing work or other activities as a result of your symptoms In this paper, CTS symptoms combined with other work-related musculoskeletal injuries are referred to as combined physical symptoms.

Data Analysis

Results of the survey were analyzed using SPSS/PC+ (SPSS Inc., Chicago, Ill). Descriptive statistics were used to show frequency distributions, percentages, arithmetic mean, median, mode variance, and standard deviation of age, gender, work load and intensity, specific procedural arithmetic, median, mode, variance, and standard deviation of age, gender, work load and intensity, specific procedural techniques, physical activities, health status and occurrence of combined physical symptoms. The χ^2 statistic was used to determine significant differences between observed frequencies of gender, work load duration and intensity, procedural techniques, combined physical activity, physical symptoms, and the expected frequencies. The Pearson product-moment correlation coefficient was used to compare the level of physical symptoms with age, years worked, and specific procedural techniques. The number of symptoms experienced were categorized into three levels as no symptoms, low symptoms (1–4 symptoms), and high symptoms (>5 symptoms).

Results

A response rate of 47% with a total of 101 respondents was achieved. Seventy-two percent of respondents were female. The mean age of all respondents was 37.9 ± 7.1 years. Table 1 lists pooled frequencies for three groupings of symptom types. Between one and four CTS symptoms were experienced by 57% of all respondents. A total of 63% of all respondents have experienced CTS symptoms at some point in their careers. Seventeen percent of respondents reported having missed work because of their symptoms, 31% have received treatment for their symptoms, 4% have received workers' compensation as a result of their symptoms, and 3% have been diagnosed with CTS.

Table 2 lists the normalized frequencies of symptoms experienced according to gender and workplace setting. Symptom level frequencies are normalized by the number of samples in each group. Men tended to experience fewer combined physical symptoms than women ($\chi^2 = 5.32$ $P = .0698$). Because of the low number of respondents in individual categories, no meaningful analyses of the effect of workplace setting could be done.

Table 3 lists the frequencies of symptoms experienced according to number of days worked per week and number of hours worked per day. The majority of respondents (89.1%) worked full time (4 or more days per week) for 6 or more hours per day. No significant relations between work load duration or intensity were found; this may be due to the low numbers of respondents who worked less than full time. Table 4 lists the normalized frequencies of symptoms experienced according to the number of cardiac ultrasound procedures performed per day and the average examination time per patient. No significant relations between the number of cardiac procedures or average examination were found. However, there appears to be a trend relating the average examination per patient to the frequency of high symptoms experienced; longer examinations tended to result in greater frequencies of high symptoms experienced.

No significant relations between aspects of general medical history and incidence of physical symptoms were

TABLE 1
Pooled Frequencies for Three Groups of Symptom Types (n = 101)

Symptom Types	Symptoms Experienced*		
	No Symptoms	Low Symptoms	High Symptoms
All physical symptoms	14%	44%	42%
CTS symptoms	37%	57%	6%
Other work-related musculoskeletal injuries	20%	55%	25%

* No symptoms = 0 symptoms reported; low symptoms = 1 to 4 symptoms reported; high symptoms = ≥5 symptoms reported.

TABLE 2
Normalized Frequencies for Number of Symptoms by Gender and Workplace Setting (n = 101)

Symptoms Experienced	Gender		Workplace Setting			
	Female (n = 73)	Male (n = 28)	Clinic (n = 8)	Office (n = 9)	Hospital (n = 76)	Other (n = 8)
No symptoms	7 (9.6%)	7 (25.0%)	25.0%	22.2%	11.8%	12.5%
Low symptoms	31 (42.5%)	13 (46.4%)	12.5%	44.5%	47.4%	37.5%
High symptoms	35 (47.9%)	8 (28.6%)	62.5%	33.3%	40.8%	50.0%

TABLE 3
Normalized Frequencies for Number of Symptoms by Number of Days Worked Per Week and Average Number of Hours Worked Per Day (n = 101)

Symptoms Experienced	Days Worked Per Week				Average Hours Worked Per Day			
	<3 days (n = 3)	3–4 days (n = 8)	4–5 days (n = 62)	>5 days (n = 28)	<3 h (n = 2)	3–5 h (n = 12)	6–8 h (n = 50)	>8 h (n = 37)
No symptoms	33.3%	12.5%	9.7%	21.4%	0.0%	8.3%	14.0%	16.3%
Low symptoms	66.7%	37.5%	41.9%	46.4%	50.0%	33.3%	44.0%	45.9%
High symptoms	0.0%	50.0%	48.4%	32.2%	50.0%	58.4%	42.0%	37.8%

TABLE 4
Normalized Frequencies for Number of Symptoms by Average Number of Cardiac Ultrasound Procedures Performed Per Day and Average Examination Time Spent Per Patient (n = 101)

Symptoms Experienced	Cardiac Ultrasound Procedures Performed Per Day					Average Time Per Patient			
	<3 (n = 13)	3–4 (n = 15)	5–6 (n = 31)	7–8 (n = 20)	>8 (n = 20)	<15 min (n = 2)	15–30 min (n = 42)	31–45 min (n = 41)	46–60 min (n = 16)
No symptoms	15.4%	20.0%	9.6%	15.0%	10.0%	0.0%	16.7%	14.6%	6.2%
Low symptoms	38.4%	40.0%	45.2%	40.0%	55.0%	0.0%	54.7%	39.0%	31.3%
High symptoms	46.2%	40.0%	45.2%	45.0%	35.0%	100.0%	28.6%	46.4%	62.5%

found; this may be due to the low numbers of respondents displaying specific symptoms. Thirty-seven percent of the female respondents reported having been pregnant at some time during their career as a sonographer. Having been pregnant at some time during their career did not significantly affect the level of symptoms experienced by female sonographers.

The sonographer's physical activity did not significantly affect the symptoms experienced. Twenty-six percent of the respondents reported exercising for at least 20 minutes one or fewer times per week, 44% exercised 2 to 3 times per week, 29% exercised 4 to 5 times each week, and only 2% exercised between 6 and 7 times each week. No strong trends between physical activity and symptoms were seen.

Statistical information regarding the average age and years of sonographer employment is given in Table 5. The correlation between combined physical symptoms (ie, back and neck and CTS symptoms) and age and years of employment was not significant.

Table 6 shows the relations between upper extremity variations (wrist motions and hand grip pressure) and incidence of CTS symptoms. Twisting and pushing motions did not correlate strongly with CTS symptoms. There was a positive correlation between CTS symptoms and using high grip pressure in the cardiac ultrasound technique ($r = .252$, $P = 0.013$). In contrast, the correlations of medium and low pressure with CTS symptoms,

TABLE 5
Statistical Analysis for Age and Number of Years Worked (n = 101)

Variable	Mean (y)	SD	Range (y)	Correlation with All Physical Symptoms	
				r	*P*
Age	37.9	7.1	22–57	−.013	.897
Years of working					
Full-time	9.2	4.5	1.5–18.0	.106	.297
Part-time	4.4	3.6	1.0–11.5	.061	.781

TABLE 6
Statistical Analysis for Wrist Motions and Hand Grip (n = 97)

Variable	Mean (%)	SD	Range (%)	Correlation with CTS Symptoms	
				r	*P*
Wrist motions					
Twist	51.5	27.1	0–100	.186	.069
Push	48.5	27.0	0–100	−.183	.073
Hand grip					
High pressure	24.3	24.5	0–90	.252	.013
Medium pressure	44.2	25.9	0–100	−.103	.317
Low pressure	31.5	29.1	0–100	−.116	.276

although not significant, were negative ($r = -.103$ and $r = -.116$, respectively).

Table 7 lists the statistical information regarding working position and posture in relation to the occurrence of other work-related musculoskeletal injuries. Posture had a significant influence. Upright posture correlated negatively ($r = -.462$, $P < .0005$) and twisted posture correlated positively with physical symptoms ($r = .315$, $P \leq .002$) with these injuries.

Discussion

The rate of response (47%) to the questionnaire was moderate, yet it was a limitation of the study. The small number of respondents in various categories limited the analysis of some data. In addition, the members of the American Registry of Diagnostic Medical Sonographers surveyed may not be representative of all cardiac sonographers. Hence, some caution should be exercised in interpreting results.

The prevalence rates of combined physical symptoms were self-reported and were not based on clinical evidence. Nonetheless, the level of reported symptoms is possibly indicative of CTS and other work-related injuries and is not trivial and should not be disregarded.[12] Eighty-six percent of the respondents reported having at least one or more combined physical symptoms. This figure is not uncommon in comparison with other work environments that require the worker to perform repetitive motions on a relatively continuous basis with static and dynamic loading of the neck, back, shoulders, and upper limbs.[17,18] Rundcrantz et al[5] reported that 72% of dentists surveyed had pain and discomfort in the neck, shoulders, and head.

Of the 63% reporting they currently have or have had CTS symptoms, only 3% have actually been diagnosed for CTS. In comparing this figure with other fields, one study suggested that up to 15% of workers in the highest risk industries (eg, meat packers, computer workers) are affected annually.[25] Another study reported that 1.1% of 2261 textile workers surveyed were diagnosed with CTS.[13] However, symptoms of other work-related musculoskeletal injuries (back and neck) were reported by 80% of respondents. Back pain is one of the major health problems in industrialized countries, afflicting 80% to 90% of the population at some time during their lives.[26] Therefore, it is reasonable that cardiac sonographers display more back and neck symptoms than CTS symptoms.

One major concern in today's industrial society is the rising rate of compensation claims, missed work, and medical expenses. An estimated 24% of sick-leave days are due to back, neck, and shoulder pain.[27] Costs exceeding $15,000 per worker including medical and indemnity expenses have been reported as a result of work-related disorders.[28] Even though the majority of respondents reported having physical symptoms, only 17% missed work, 31% had received treatment, and 4% were receiving workers' compensation as a result of their symptoms. The low correlations between combined physical symptoms and work load and intensity and cardiac procedural techniques leave questions about which specific variable(s) contribute to these physical symptoms. This lack of strong correlation may explain why the number of days missed, the percentage of sonographers seeking treatment for symptoms, and the percentage of persons receiving workers' compensation are relatively low compared with workers in professions who are at a high risk for work-related injuries.

The literature suggests, at least in part, that ergonomic factors, equipment, and specific work techniques are associated with CTS symptoms and other work-related disorders.[1] Even though the results showed minimal relation between various work environments, specific procedural techniques, and reported physical symptoms, a few variables had trends that are supported by the literature. In comparing wrist motions, both the twisting and pushing motions tended to correlate positively with CTS symptoms, but were not significant at $P \leq .05$. In comparing hand grip pressure with CTS symptoms, high-pressure grip had a significant effect and a positive correlation. This indicates that a high grip pressure may lead to CTS symptoms. Both medium pressure and low pressure did not yield significant values, but both had negative correlations. This coincides with the results of studies that show that increased applied force leads to increased likelihood of developing musculoskeletal injuries.[25,28]

Upright posture correlated significantly with other work-related musculoskeletal injuries. This study also revealed a significant positive correlation between twisted positions and other work-related musculoskeletal injuries. The hunched-over and combination postures did not show significance but had positive correlations. These results indicate that a balanced posture reduces the incidence of symptoms experienced. In a balanced posture (upright), the disc, joints, muscles, and ligaments are under the least amount of stress. Moving out of

TABLE 7
Statistical Analysis for Working Position and Posture (n = 97)

Variable	Mean (%)	SD	Range (%)	Correlation with Other Work-related Musculoskeletal Injuries	
				r	*P*
Working position					
Sit	72.3	31.4	0–100	−.077	.454
Stand	27.7	30.8	0–100	.053	.606
Posture					
Upright	42.4	35.2	0–100	−.462	.0005
Twisted	28.4	27.2	0–100	.315	.002
Hunched over	13.1	18.1	0–90	.076	.459
Combination of above postures	17.1	30.1	100	.174	.088

that balance places stress on certain anatomic structures.[18]

Standing had a positive correlation. These results support Craig's findings that scanning a patient while seated as opposed to standing leads to decreased symptoms experienced by sonographers.[4]

This study also revealed little relation between combined physical symptoms and work load and intensity, age, gender, various physical activities, and health status. Gender did, however, display a strong trend with combined physical symptoms. Significant differences between men and women have been found in muscle motor performance and strength.[22,29] A stronger person may be able to hold the ultrasound transducer against the patient with less perceivable hand grip pressure than a weaker person. That is, even though the absolute grip pressure may be equal, the strong person may perceive a lower relative magnitude grip pressure than the weak person. It is possible that the trend for gender difference in physical symptoms displayed may reflect the significant positive correlation of high hand grip pressure with physical symptoms.

Average examination (or duration) per patient did exhibit a trend in relation to the frequency of high physical symptoms experienced. Other studies have shown that duration of work without rest can be a contributing factor to the development of musculoskeletal disorders.[17] Data from a larger number of respondents are required to elucidate this relation for sonographers.

It should be noted that cardiac sonography is relatively new and, as a result, many physical symptoms usually associated with work environments and procedural techniques may not yet be present. Therefore, it will be important to monitor the physical symptoms of cardiac sonographers in the future to determine whether there are specific factors that contribute to disorders that are unique to cardiac sonographers.

Conclusion

The multitude of factors that may contribute to physical symptoms makes it hard to pinpoint which factors, if any, are the primary causes of cardiac sonographers' musculoskeletal problems. Some specific techniques and postures, however, show a strong relation to the number of symptoms experienced by cardiac sonographers.

Emphasis should be placed on equipment and work environments that allow the cardiac sonographer to maintain joints in optimum positions, maintain balanced postures, and allow frequent breaks to give soft tissues a chance to recuperate from awkward positions and repetitive movement. These are factors that can be modified by the equipment manufacturers and administrators. Physical activity and general health status are dependent upon the individual sonographer. Preventive education is a key factor in helping workers maintain and learn how to maintain their health. Perhaps, with the cooperation of the equipment manufacturers, administrators, and the cardiac sonographer, the musculoskeletal problems now experienced will be decreased and cardiac sonographers who are experiencing these difficulties can return to a healthier life.

References

1. Stock SR. Workplace ergonomic factors and the development of musculoskeletal disorders of the neck and upper limbs: a meta-analysis. *Am J Ind Med.* 1991; 19:87–107.
2. Phalen G. The carpal tunnel syndrome. *J Bone Joint Surg.* 1966;48A:211–228.
3. Craig M. Sonography: an occupational health hazard. *J Diagn Med Sonogr.* 1985;3:121–125.
4. Craig M. Occupational hazards of sonography: an update. *J Diagn Med Sonogr.* 1990;1:47–50.
5. Rundcrantz BL, Johnsson B, Moritz U. Cervical pain and discomfort among dentists: epidemiological, clinical and therapeutic aspects. *Swed Dent J.* 1990;14:71–80.
6. Harber P, Shimoazki S, Gardner G. Importance of non-patient transfer activities in nursing-related back pain. II. Observational study and implications. *J Occup Med.* 1987;29:971–974.
7. Conrad JC. Osborn JB, Conrad KJ. Peripheral nerve dysfunction in practicing dental hygienist. *J Dent Hyg.* 1990; 54:382–387.
8. Thompson JS, Phelps TH. Repetitive strain injuries: how to deal with the epidemic of the 1990's. *Postgrad Med.* 1990;88:143–149.
9. Polakoff PL. Repetitive motion, radiation and eye concerns mount at computer worksites. *Occup Health Safety.* 1991;60:34,50.
10. Harmon SE. Occupational dieases of instrumental musicians, literature review. *Maryland State Med J.* 1982;31:39–42.
11. Revak J. Incidence of upper extremity discomfort among piano students. *Am J Occup Ther.* 1989;43:149–154.
12. Margolis W, Kraus J. The prevalence of carpal tunnel syndrome symptoms in female supermarket checkers. *J Occup Med.* 1987;29:953–956.
13. McCormack RR, Inman RD, Wells A. Prevalence of tendinitis and related disorders of the upper extremity in manufacturing workforce. *J Rheumatol.* 1990;17:958–964.
14. Barnhart S, Demers PA, Miller M. Carpal tunnel syndrome among ski manufacturing workers. *Scand J Work Environ Health.* 1991;17:46–52.
15. Viikari JE, Durppa K, Huuskonen M. Prevalence of epicondylitis and elbow pain in the meat-processing industry. *Scand J Work Environ Health.* 1991;17:38–45.
16. Hedberg GE. The period prevalence of musculoskeletal complaints among Swedish professional drivers. *Scand J Soc Med.* 1988;16:5–13.
17. Browne CD, Nolan BM, Faithfull DK. Occupational repetition strain injuries: guidelines for diagnosis and management. *Med J Aust.* 1984;140:329–332.
18. Saunders HD. *Basic Spinal Biomechanics.* Minneapolis, Minn: Viking Press Inc; 1985:77–84.
19. Hertling D. *The Spine: General Structure and Biomechanical Considerations.* 2nd ed. Philadelphia, Pa: J. B. Lippincott Company; 1990:451–494.
20. Hagberg M. Work load and fatigue in repetitive arm elevation. *Ergonomics.* 1981;24:543–555.
21. Strasser H, Keller E. Local muscular strain dependent on the direction of horizontal arm movement. *Ergonomics.* 1989;32:899–910.
22. Asmussen E, Heebol-Nielsen K. Isometric muscle strength of adult men and women. *Communication from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis.* 1961;11:1–41.
23. Knapik JJ, Wright RH, Mawdsley RH. Isometric, isotonic and isokinetic torque variations in four muscle groups through a range of joint motion. *Phys Ther.* 1983;63:938–942.
24. Yates JW, Kammon E, Rodgers SH. Static lifting strength and maximal iso-

metric voluntary contractions of back, arm, and shoulder muscles. *Ergonomics.* 1980;23:37–47.
25. Silverstein BA, Fine LJ, Armstrong TJ. Occupation factors in carpal tunnel syndrome. *Am J Indust Med.* 1987;11:343–358.
26. Frymoyer JW, Gordon SL, eds. *New Perspectives on Low Back Pain.* Park Ridge, Ill: American Academy of Orthopedic Surgeons; 1989;373–390.
27. Kellett KM, Kellet DA, Nordholm LA. Effects of an exercise program on sick leave due to back pain. *Phys Ther.* 1991;71:283–292.
28. Masear VR, Hayes JM, Hyde AG. An industrial cause of carpal tunnel syndrome. *Hand Surg Am.* 1986;11:222–227.
29. Sheperd AH, Abbey DS, Humphries M. Age and sex in relation to perceptual motor perforance on several control-display relationships on the TCC. *Perceptual Motor Skill.* 1958;8:327–330.