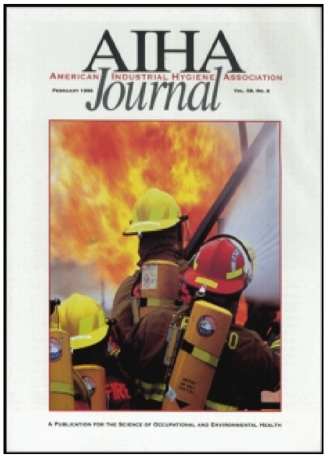

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THE STRAIN INDEX: A PROPOSED METHOD TO ANALYZE JOBS FOR RISK OF DISTAL UPPER EXTREMITY DISORDERS

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Based on existing knowledge and theory of the physiology, biomechanics, and epidemiology of distal upper extremity disorders, a semiquantitative job analysis methodology was developed. The methodology involves the measurement or estimation of six task variables (intensity of exertion, duration of exertion per cycle, efforts per minute, wrist posture, speed of exertion, and duration of task per day); assignment of an ordinal rating for each variable according to exposure data; then assignment of a multiplier value for each variable. The Strain Index is the product of these six multipliers. Preliminary testing suggests that the methodology accurately identifies jobs associated with distal upper extremity disorders versus jobs that are not; however, large-scale studies are needed to validate and update the proposed methodology.

The evaluation of exposure for distal upper extremity musculoskeletal stressors has generally focused on determining the presence of one or more generic risk factors.(1-4) Only a few studies have attempted to quantify their intensity or examine their interactions.(5-12) As a result, exposure assessment related to the identification of distal upper extremity hazards is usually subjective and often lacks standardization.

There are several circumstances where a more standardized methodology would be helpful. For example, decisions on the work-relatedness of a disease should be based on exposure assessment arising from job analysis rather than on someone's subjective opinion.(13) Similarly, a conclusion regarding the presence of a hazardous exposure should rely on results of a job analysis.

OPTIONS FOR DETERMINING SAFE VERSUS HAZARDOUS JOBS

The terms "safe" and "hazardous" describe jobs. Hazardous jobs expose workers to one or more musculoskeletal stressors of sufficient intensity, frequency, and/or duration so that the workers are at increased risk for musculoskeletal disorders. "Safe" implies that the job is not hazardous–e.g., exposed workers are not at increased risk. "Safe" does not imply no exposure. At present, there are four options to determine whether a job is safe or hazardous. These are (1) professional opinion based on subjective judgment and past experience; (2) determination of some physiological, biomechanical, or psychophysical critical threshold response (e.g., disc compressive force for low-back pain);(14) (3) epidemiological data that associates job, task, and/or individual variables with some manifestation of increased risk of a disorder; or (4) some combination of these three (e.g., the revised National Institute for Occupational Safety and Health [NIOSH] equation for manual handling tasks).(15)

Professional judgment from highly qualified job analysts is very desirable and probably cannot be replaced by any model; however, it is subjective and can be influenced by personal bias. Since a large number of people with varying educational and background experiences (ergonomists, industrial hygienists, safety professionals, physicians, nurses, physical therapists, occupational therapists, etc.) are called on to determine whether a job is safe or hazardous, differences of opinion are expected. Some may call a job extremely hazardous while others call it totally safe. Since the exposure assessment process is entirely subjective, there is no objective means of resolving these differences of opinion.

As far as distal upper extremity disorders are concerned, there is a lack of practical physiological, biomechanical, or psychophysical models that relate job risk factors to increased risk of developing such disorders. This is probably because (1) dose-response (cause-effect) relationships are not well understood; (2) measurement of some task variables, such as force, is very difficult in an industrial setting; and (3) the number of task variables is very large.

Some epidemiological data associate job and/or task variables with increased prevalence or incidence of distal upper extremity disorders; however, there are only a handful of such studies.(6,7,11) Large-scale controlled studies are lacking. In general, these studies have shown that force and repetitiveness are important risk factors, while the importance of wrist posture is questionable.

Even though controlled scientific studies are lacking, it is generally accepted that force, repetition, posture, recovery time, and type of grasp are important factors in the causation of distal upper extremity disorders.(1-12) Other job factors that may increase risk, in combination with the other factors, include cold temperature, use of gloves, use of vibrating tools, etc.(1–3) Duration of exposure, static muscular work, and use of the hand as a tool, while not studied in detail with regard to distal upper extremity disorders, are also generally accepted as risk factors.

At the present time, there are some who doubt that jobs cause distal upper extremity disorders, especially carpal tunnel syndrome (CTS), because of the lack of epidemiological association between job risk factors and CTS (including surrogate measures for CTS).(16–18) At the other extreme, there are others who call a job "hazardous" simply on the basis of observing the presence of a single generic risk factor—e.g., non-neutral wrist postures or repetition rate greater than twice per minute. While the latter group will probably never miss identification of a truly "hazardous" job, one must question how many safe jobs have been or will be erroneously classified as hazardous.

One could argue that it is not appropriate to propose a job analysis methodology to estimate the risk of workers developing distal upper extremity disorders if the exact pathogenetic mechanisms are not clearly understood. On the other hand, if no such methodologies are proposed and provided to ergonomic practitioners, then they must continue to rely on their subjective judgment (e.g., identification of non-neutral wrist posture and/or more than two repetitions per minute, etc.) as sufficient cause for determining that a job is hazardous. In addition, the type of database needed to understand the dose-response relationships for distal upper extremity disorders is unlikely to become available in the foreseeable future. Thus, on the practical side, there is a need to provide semiquantitative or quantitative job analysis methodologies to ergonomics practitioners to discriminate between safe and hazardous jobs in terms of workers being at increased risk of developing distal upper extremity disorders. It should be recognized, however, that such methodologies are first attempts, they have limitations, and they need to be validated and revised as new data become available. Others also have proposed semiquantitative methodologies to determine safe versus hazardous jobs for distal upper extremity disorders.(8–10,12,19,20)

This article presents a proposed semiquantitative job analysis methodology that, based on preliminary testing, appears to identify accurately jobs associated with distal upper extremity disorders versus jobs that are not. The methodology, while designed to be relatively simple to use, is based on principles of physiology, biomechanics, and epidemiology as related to distal upper extremity disorders.

DISTAL UPPER EXTREMITY DISORDERS

The term "cumulative trauma disorders" (CTDs) often is used to describe symptoms or disorders believed to be related to various anatomical structures and/or tissues in the body. From a musculoskeletal perspective, symptoms are perceived sensations and disorders are morbid physical states.(21) While suggestive, symptoms may or may not be associated with disorders arising from cumulative trauma—i.e., by themselves, they lack diagnostic specificity. In a literal sense, CTDs are not limited to the distal upper extremity (elbow, forearm, wrist, and hand).

In addition, the term "CTDs" infers a single specific pathogenetic mechanism, the accumulation of trauma. This may not be correct. For example, stenosing tenosynovitis affecting the first dorsal compartment of the wrist (the thumb side) is called DeQuervain's tenosynovitis. It is considered a CTD. Schneider defined DeQuervain's tenosynovitis as passive functional hypertrophy of the fibrous layer of the tendon sheath(s) of the abductor pollicis longus (APL) and/or extensor pollicis brevis (EPB) that causes stenosis of the sheath over the radial styloid and impaired thumb function.(22) The pathogenetic mechanism of this disorder is not traumatic. It is a normal biological adaptation (passive functional hypertrophy) believed to be secondary to prolonged repeated movements or deviations of the wrist with the thumb fixed on an object.(23–27) Since the term "CTD" lacks diagnostic specificity, anatomical specificity, and may erroneously associate symptoms or disorders with a specific pathogenetic mechanism, its use will be deferred in this article. Instead, the phrase distal upper extremity disorders is used.

The distal upper extremity contains a number of tissues. In simplistic terms, these include skin, subcutaneous tissue, blood vessels, nerves, bones, joints, and muscle-tendon units. For distal upper extremity disorders related to work, the most common target tissues are the muscle-tendon units and nerves. A muscle-tendon unit is a composite structure that includes muscle, tendon, tendon sheaths, myotendinous junctions, and tendon-bone junctions.(28) Each component of the muscle-tendon unit has unique physiological and biomechanical properties, and each is associated with unique disorders or manifestations of strain. Examples include tendinitis, peritendinitis, delayed-onset muscular soreness, muscle strains, localized muscle fatigue, and stenosing tenosynovitis (e.g., DeQuervain's tenosynovitis, trigger finger, trigger thumb, etc.). It is also commonly assumed that distal upper extremity symptoms, such as discomfort or pain, are related to the muscle-tendon units of the distal upper extremity. (Readers interested in greater detail on this subject are referred to reference 28.)

CTS is the most common of the nerve disorders and has received the most attention. While the exact cause of CTS is not clear, mechanical compression of the median nerve in the carpal tunnel with persistent nerve conduction impairment is believed to be the most dominant theory.(29) In terms of the relationship between CTS and hand/wrist activity, theories regarding the origin of the nerve compression include compression via tendon hypertrophy;(29) compression from loaded tendons, especially when the wrist is deviated from a non-neutral posture;(30) compression by thickening of the transverse carpal ligament;(31–34) and compression by altered tendon sheaths.(35–40) Compression of the median nerve is mediated in each instance by effects from or changes in components of the muscle-tendon units associated with the carpal tunnel.

Several authors have presented distal upper extremity morbidity data (symptoms and/or disorders) that were associated with jobs believed to pose increased risk.(5,11,41–47) When considered together, there is a consistent pattern of morbidity (e.g., symptoms and/or disorders related to muscle-tendon units constitute a much greater percentage of distal upper extremity morbidity than CTS).(5, 11,41–48) In addition, when CTS appears to be associated with such jobs, it is almost always associated with other muscle-tendon unit disorders in the referent case or other workers performing the job—i.e., "co-morbidity."(5,11,41–48)

One objective of the proposed Strain Index methodology is to discriminate between jobs that do versus jobs that do not expose workers to musculoskeletal risk factors (task variables) that cause the types of distal upper extremity disorders discussed above. The occurrence of these disorders may be suspected on the basis of reported symptoms and confirmed with clinical evaluations. Their occurrence also may be detected by reviewing medical records or related documentation.

The proposed Strain Index has not been developed or tested for its ability to identify jobs associated with increased risk of any single specific disorder, such as CTS. It is anticipated that jobs identified to be high risk by the Strain Index will exhibit a spectrum of distal upper extremity morbidity among workers who currently perform or historically performed those jobs. Since disorders of the muscle-tendon units are the most commonly observed disorders associated with jobs believed to be hazardous, they should be the most commonly observed disorders among jobs identified to be high risk by the Strain Index. Similarly, symptoms related to those disorders should be the most commonly reported symptoms. Other outcomes, such as high turnover, are also potential indicators of a high-risk job that could correlate with the presence of a hazard and account for a lack of observed distal upper extremity morbidity under certain circumstances.

The Strain Index is a tool to assess jobs. It is not a tool to assess people. It attempts to answer the question "Is a particular job hazardous or safe?" in terms of the occurrence of distal upper extremity morbidity among a cohort of workers that do or did perform the job.

THE SCIENTIFIC BASIS FOR STRAIN INDEX

This section presents a review of the physiological, biomechanical, and epidemiological knowledge on which the Strain Index was developed. The Index methodology was not derived using explicit mathematical relationships from experimental studies, but rather by using the principles from these disciplines.

Physiological Considerations and Job Risk Factors (Task Variables)

For the distal upper extremity the primary physiological endpoint of interest is localized muscle fatigue. Simonson defined fatigue as the transient loss of work capacity resulting from preceding work.(49) It is a reversible physiological state. The exact cause is unknown, but it may involve accumulation of waste products, depletion of energy reserves, or hypoxemia secondary to impaired blood flow into the contracted muscle.(49) Symptoms of localized muscle fatigue may include sensations of exhaustion, discomfort, or fatigue; increased perceived exertion; decreased strength; or loss of neuromuscular control.(50) While the relationship between localized muscle fatigue and specific disorders of the distal upper extremity has not been clearly elucidated, it appears to play a significant role in the pathogenesis of some conditions (e.g., peritendinitis).(51)

For a single exertion, the amount of localized muscle fatigue and its rapidity of onset depends on intensity and duration of exertion.(52) Intensity of exertion is expressed as a percentage of maximal strength:

$$\%\text{Maximal Strength} = 100 * \frac{\text{(Required Strength)}}{\text{(Worker's Maximal Strength)}} \quad \textbf{(1)}$$

Since maximal strength varies among a population of individuals, but required strength is constant, this expression reflects increased strain among weaker members of the population. Further, maximal strength is task-specific—e.g., if the task requires applying force with a deviated wrist and pinch grasp, maximal strength should be measured or estimated in those postures. Pinch grasp, non-neutral wrist postures, and increasing speed of work decrease maximal strength.(53–61) These increase the intensity of the exertion, thus increasing the rapidity of onset of localized muscle fatigue—a physiological manifestation of strain.

Endurance time represents the duration of exertion prior to the onset of some manifestation of fatigue. Hagberg, using electromyography (EMG), found that endurance times (in seconds) for isometric and dynamic contractions were related to percentage of maximal strength as in Equations 2 and 3, respectively,(62)

$$\text{Endurance Time}_{\text{ISO}}\ (\text{sec}) = \frac{341{,}123}{(\%\text{MS})^{2.14}} \quad \textbf{(2)}$$

$$\text{Endurance Time}_{\text{DYN}}\ (\text{sec}) = \frac{324{,}487}{(\%\text{MS})^{2.23}} \quad \textbf{(3)}$$

where %MS = percentage of maximal strength as defined in Equation 1. Since endurance time is inversely proportional to strain on the muscle (one component of a muscle-tendon unit), physiological strain is approximately proportional to the square of the intensity of exertion.

For repeated exertions, endurance time is related to the intensity of exertion, duration of exertion, and duration of relaxation.(63,64)

In summary, the following major principles are derived from the physiological model of localized muscle fatigue:

(1) The primary task variables are intensity of exertion, duration of exertion, and duration of recovery.
(2) Intensity of exertion refers to the force required to perform a task one time. It is characterized as a percentage of maximal strength.
(3) Duration of exertion describes how long an exertion is applied. The sum of duration of exertion and duration of recovery is the cycle time of one exertional cycle.
(4) Wrist posture, type of grasp, and speed of work are considered via their effects on maximal strength.
(5) The relationship between strain on the body (endurance time) and intensity of exertion is nonlinear.(62–64)

Biomechanical Considerations and Job Risk Factors (Task Variables)

The muscle-tendon units in the distal upper extremity may experience two types of forces, tensile and compressive. A tensile load acts along the longitudinal axis of the muscle-tendon unit while a compressive load acts perpendicular to some part of the muscle-tendon unit. Tensile load is a result of activation of the contractile element of the muscle plus passive forces related to stretching the elastic elements of the muscle-tendon unit. The contractile force is related to intensity of exertion, speed of exertion, and posture. The passive force is related to elongation of the muscle-tendon unit secondary to posture and nonvoluntary external force.

Muscle-tendon units are viscoelastic structures. Investigations of the viscoelastic properties of muscle-tendon units (or their components) involve comparing the elongation (stretching) of the structure to varying levels of applied tensile load. The tensile load can be expressed as force, but it is more common to divide the force by the cross-sectional area of the structure being tested. This latter variable is called "stress" and has units of force per unit area. Elongation usually is expressed as a percentage increase in length compared to the resting length and is called "strain."

Studies of the elastic properties of tendon show that, within the elastic limit, strain is nonlinearly proportional to stress.(65,66) Under repeated loading, permanent deformation (permanent elongation) is not observed, provided the strain does not exceed the elastic limit.(67) Under normal physiological conditions, tendon strain is below the elastic limit, so it is not subject to tensile loads that would permanently deform it much less cause its fibers to fray or fail.(67–69) Viscous properties of tendon show that tendons can withstand larger loads when applied rapidly (high strain rate), plus they exhibit stress relaxation, creep, and hysteresis.(67) These elastic and viscous responses of components of the muscle-tendon units are related to the magnitude and duration of the tensile load, strain rate, number of cycles of repeated loading, and duration of recovery intervals. While not known with certainty, it has been postulated that they may play an important role in the causation of distal upper extremity disorders.(66)

Compressive loads on a muscle-tendon unit may be intrinsic or extrinsic.(28) An extrinsic force arises external to the body and impacts upon a critical tissue, such as a muscle-tendon unit, nerve or blood vessel. Blunt traumatic injuries and forcefully grasping a square-handled tool are examples of extrinsic compression. The Strain Index does not incorporate task variables that account for extrinsic compression. Disorders due to extrinsic compression, such as hypothenar hammer syndrome and some cases of CTS, are well documented.(70–73) A comprehensive job analysis system should include an assessment of extrinsic compression in addition to tools such as the proposed Strain Index.

An intrinsic compressive force arises when a loaded tendon turns a corner. The magnitude of this intrinsic compression is related to the magnitude of the tensile load, the radius of curvature of the surface around which the tendons angle (wrist posture), and the length of arc of contact between the tendon and the supporting surface.(74) Since the non-bony surfaces around which the tendons turn corners in the distal upper extremity correspond to specific supporting structures (the transverse carpal ligament, the A-1 pulleys, or the six dorsal compartments covered by the extensor retinacula), the length of arc of contact is essentially constant. As a result, intrinsic compressive forces primarily arise from exertions in non-neutral wrist postures. The importance of some of these factors has been demonstrated epidemiologically.(2)

In summary, the following are major principles derived from the biomechanical model of the viscoelastic properties of components of a muscle-tendon unit:

(1) The primary task variables for the viscoelastic properties are intensity and duration of exertion, duration of recovery, number of exertions, wrist posture, and speed of work.
(2) The primary task variables for intrinsic compression are intensity of exertion and non-neutral wrist posture.
(3) The relationship between strain on the body and intensity of effort is nonlinear.(65,66)

Epidemiological Considerations and Job Risk Factors (Task Variables)

Several job factors have been reported in the literature to be related to or associated with distal upper extremity disorders. These include forceful exertions, high repetition, awkward posture, insufficient recovery time, pinch grasp, hand-arm vibration, cold temperature, poorly fitting gloves, unaccustomed work, poorly designed hand tools, repeated pronation and supination of the forearm, mechanical stress concentrations, etc.(1–9,11,12,75) However, the vast majority of these citations are anecdotal (e.g., case reports or case series). In general the task variables in the case reports and case series were described qualitatively rather than quantified and, in some circumstances, it is not clear if the tasks were actually observed. Some studies measured the prevalence of symptoms rather than the incidence of disorders. Others arbitrarily classified jobs as repetitive, requiring forceful exertions, or using awkward postures without clear definitions. As a result it is difficult to utilize the vast majority of this data to develop a semiquantitative system. Maybe because of this, some researchers have advocated the use of checklists.(12,75)

One of the most frequently cited epidemiological studies of the relationship between job risk factors and distal upper extremity disorders was published by Silverstein et al.(6) This study found that the prevalence of CTS was associated with jobs characterized as highly forceful and highly repetitive. Repetitiveness appeared to be a stronger factor than forcefulness. Awkward hand/wrist posture, often cited as a generic risk factor, was not found to be a significant predictor of the prevalence of CTS. Hand-arm vibration was not associated with the prevalence of CTS after accounting for the exertional demands of the jobs. In a related publication that relied on the same exposure assessment methodology, Armstrong et al. found that the prevalence of hand-wrist tendinitis in workers who performed highly repetitive and forceful jobs was 29 times greater compared to those who performed jobs low in repetitiveness and forcefulness.(7) For these disorders, however, high forcefulness was more significant than repetitiveness. Once again, hand/wrist posture and vibration were not associated with the prevalence of hand-wrist tendinitis.

Moore and Garg compared exposure factors for jobs associated with upper extremity disorders to jobs without such disorders.[11] They found that the intensity of exertion, estimated as a percentage of maximal strength and adjusted for wrist posture and speed of work, was the major differing factor. Wrist posture was independently significant, but at a lower level. Using regression techniques, the relationship between the incidence rate for distal upper extremity disorders and the job risk factors was:

$$IR = \frac{30*F^2}{RT^{0.6}} \tag{4}$$

where IR = incidence rate (per 100 workers per year); F = intensity of exertion (%MS); and RT = recovery time (percentage of cycle time).

In summary, the following are the major principles derived from the epidemiological literature:

(1) The primary task variables associated with an increased prevalence or incidence of distal upper extremity disorders are intensity of exertion (force), repetition rate, and percent of recovery time per cycle.

(2) Intensity of exertion was the most important task variable in two of the three studies explicitly mentioned.[7,11] The majority (or all) of the morbidity was related to disorders of the muscle-tendon unit. The third study, which considered only CTS, found that repetition was more important than forcefulness.[6]

(3) Wrist posture may not be an independent risk factor. It may contribute to an increased incidence of distal upper extremity disorders when combined with intensity of exertion.

(4) The roles of other task variables have not been clearly established epidemiologically; therefore, one has to rely on biomechanical and physiological principles to explain their relationship to upper extremity disorders, if any.

Integration and Qualification

While each of these disciplines investigates different measures of strain on the body, and the relationships between some of these measures and disorders of the distal upper extremity are not clearly established, the consistency and coherence of the relevant task variables are notable. The task variables primarily describe the exertional aspects of the job—e.g., the intensity, repetitiveness, and duration of the exertion; the recovery time between exertions; and the wrist posture and speed associated with the exertion. While the exact relationship between the task variables and the risk of distal upper extremity disorders has not been established, it is widely agreed that these are the important risk factors for these disorders. The Strain Index methodology is based on describing jobs or tasks according to their exertional requirements. As a result, one relevant task variable not included in the Strain Index is mechanical compression of distal upper extremity tissues by extrinsic sources.

While it is obvious that many exertions performed by the distal upper extremity involve the finger flexors, such as when the hand grips an object with a power grasp, they also involve other muscle-tendon units, such as the wrist extensors. The extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris (the wrist extensors) activate to stabilize the wrist when gripping. Similarly, the APL and EPB stabilize the thumb when pinching. Given such kinesiological considerations, it is believed that the proposed Strain Index methodology has the ability to predict disorders of the muscle-tendon units throughout the distal upper extremity.

The Strain Index has been developed to predict increased risk for distal upper extremity disorders in general. It does not differentiate between specific disorders. Examples of specific disorders include medial epicondylitis, lateral epicondylitis, peritendinitis affecting the APL and/or EPB, stenosing tenosynovitis affecting the dorsal wrist compartments and the A-1 pulleys of the digits, and CTS. The Strain Index also may predict the occurrence of distal upper extremity symptoms, such as discomfort or pain, but the limitations of reliance on symptoms alone should be remembered.

It is recognized that the Strain Index has the following limitations in terms of its application to all potential distal upper extremity disorders:

(1) There are some disorders of the distal upper extremity that should not be predicted by the Strain Index—e.g., hand-arm vibration syndrome (HAVS) and hypothenar hammer syndrome.

(2) The Strain Index has not been developed to predict increased risk for distal upper extremity disorders of uncertain etiology or relationship to work. Examples include ganglion cysts, osteoarthritis, avascular necrosis of carpal bones, and ulnar nerve entrapment at the elbow.

(3) The Strain Index has not been developed to predict disorders outside of the distal upper extremity, such as disorders of the shoulder, shoulder girdle, neck, or back.

THE STRAIN INDEX

The Strain Index is a semiquantitative job analysis methodology that results in a numerical score (SI score) that is believed to correlate with the risk of developing distal upper extremity disorders. The index is based on multiplicative interactions among its task variables, consistent with physiological, biomechanical, and epidemiological principles. The SI score represents the product of six multipliers that correspond to six task variables. These are (1) intensity of exertion, (2) duration of exertion, (3) exertions per minute, (4) hand/wrist posture, (5) speed of work, and (6) duration of task per day.

The first five task variables were identified from the scientific principles. The sixth was included because the authors believe it is a relevant factor.

The authors chose to have each task variable rated according to five levels. Even though some variables could be rated on fewer than five levels (posture and speed of work), others were more appropriately rated using all five. The authors felt that use of a constant number of levels for each task variable made the

TABLE I. Rating Criteria

Rating	Intensity of Exertion	Duration of Exertion (% of cycle)	Efforts/Minute	Hand/Wrist Posture	Speed of Work	Duration per Day (hrs)
1	light	<10	<4	very good	very slow	≤1
2	somewhat hard	10–29	4–8	good	slow	1–2
3	hard	30–49	9–14	fair	fair	2–4
4	very hard	50–79	15–19	bad	fast	4–8
5	near maximal	≥80	≥20	very bad	very fast	≥8

methodology easier to use. These ratings are presented in Table I. The multipliers for each task variable are related to the ratings (Table II). The following sections explain each of the task variables and their ratings.

Intensity of Exertion

Intensity of exertion is an estimate of the force requirements of a task, reflecting the magnitude of muscular effort required to perform the task one time. Defined as the percentage of maximum strength required to perform the task once, intensity of exertion is related to physiological stress (percentage of maximal strength) and biomechanical stresses (tensile load) on the muscle-tendon units of the distal upper extremity. It does not reflect stresses related to endurance or stamina. Since tensile load cannot be measured *in vivo*, and measurement of applied force with the hand is currently impractical in an industrial setting, intensity of exertion is estimated.

The proposed methodology involves estimating the intensity of exertion using verbal descriptors (see Table I), which estimate perceived exertion. In this regard, it is similar to using the Borg CR-10 scale, but with fewer choices.(76) The methodology relies on observers to rate the intensity of exertion. There is some evidence that observers are able to effectively discriminate between different levels of perceived exertion using the Borg scale, though tending to overestimate low levels of stress and underestimate high levels compared to workers performing the task.(77) These effects were considered when the verbal descriptors in Table I were chosen. To estimate the intensity of exertion, a job analyst or ergonomics team observes a worker (or workers) perform the job, then selects the verbal descriptor from Table I that best corresponds to their perception of the intensity of exertion. The corresponding rating (1, 2, 3, 4, or 5) is then assigned using this table. Until more formal procedures are derived and evaluated, it is recommended that differences among estimates be resolved by consensus if more than one job analyst is involved.

For example, consider a job that involves the use of cutters to cut wire. The intensity of exertion refers to the strength required to use the distal upper extremity to operate the tool to cut the wire one time. The job analyst perceives that the intensity of exertion is "hard." According to Table I, this corresponds to a rating of 3. According to Table II, the multiplier is 6.0. Note that neither frequency nor duration were considered in this estimate. These factors and their effects are addressed through other task variables and their multipliers.

As a second example, consider a card dealer. In this case, the intensity of exertion associated with grasping a single card is relatively trivial. This corresponds to the lowest rating level—"light." The rating and the multiplier are both 1.0.

The multiplier values (Table II) reflect the rating score raised to a power of 1.6. A power relationship was selected for several reasons: (1) the physiological, biomechanical, and epidemiological principles suggest a nonlinear relationship between intensity of exertion and manifestations of strain; and (2) psychophysical theory suggests that perceived effort is related to applied force by a similar relationship.

In the Strain Index methodology, intensity of exertion is the most critical variable. Its unique status is demonstrated in Table II, where multiplier values for intensity of exertion are shown to be much different from those of other task variables. It is the only task variable where the multipliers are mathematically related to the rating values. The multipliers for the other task variables can be considered modifiers to the intensity of exertion multiplier. Increasing levels of intensity of exertion imply increasing levels of strain on the distal upper extremity.

Duration of Exertion

Duration of exertion reflects the physiological and biomechanical stresses related to how long an exertion is maintained. It is characterized as the percentage of time an exertion is applied

TABLE II. Multiplier Table

Rating	Intensity of Exertion	Duration of Exertion	Efforts/Minute	Hand/Wrist Posture	Speed of Work	Duration per Day
1	1	0.5	0.5	1.0	1.0	0.25
2	3	1.0	1.0	1.0	1.0	0.50
3	6	1.5	1.5	1.5	1.0	0.75
4	9	2.0	2.0	2.0	1.5	1.00
5	13	3.0[A]	3.0	3.0	2.0	1.50

[A] If duration of exertion is 100%, then efforts/minute multiplier should be set to 3.0.

per cycle. In the Strain Index methodology, the terms "cycle" and "cycle time" refer to the exertional cycle and average exertional cycle time, respectively. Since the duration of recovery per cycle is equal to the exertional cycle time minus the duration of exertion per cycle, the Strain Index methodology incorporates the epidemiological findings in Equation 4.

To measure the average exertional cycle time, a job analyst or ergonomics team observes the job (or a representative videotape of it) for a sufficient period of time to obtain a reasonable representation of the job requirements. In general, this should be several complete job cycles (the more the better). The duration of the observation period is measured with a stopwatch. The number of exertions can be counted using a counter. The average exertional cycle time is calculated by dividing the duration of the observation period by the number of exertions counted during that time period.

The duration of exertion is the average duration of exertion per exertional cycle (calculated by dividing all durations of a series of exertions by the number of observed exertions). The percentage duration of exertion is calculated by dividing the average duration of exertion per cycle by the average exertional cycle time, then multiplying the result by 100, as shown in Equation 5. The calculated percentage duration of exertion is compared to the ranges in Table I and assigned the appropriate rating. The corresponding multiplier is identified using Table II.

$$\%\text{Duration of Exertion} = 100 * \frac{(\text{Average Duration of Exertion per Cycle})}{(\text{Average Exertional Cycle Time})} \quad (5)$$

For example, if the average exertional cycle time is 30 seconds, and the average duration of exertion is 15 seconds, the percentage duration of exertion is 50%. This corresponds to a rating of 4 (Table I) and a multiplier of 2.0 (Table II). For a duration of exertion of 5%, the rating is 1, and the multiplier is 0.5. If the duration of exertion is 85%, the rating is 5 and the multiplier is 3.0.

The multiplier table values were derived using professional judgment to be consistent with the physiological and epidemiological considerations. For a given intensity of exertion and a constant number of efforts per minute, a longer duration of exertion should be associated with greater strain than a shorter duration of exertion.

The multipliers were derived empirically as demonstrated in the following example. Assume a job requires an exertion that is "somewhat hard" every 10 seconds (six efforts per minute, rating = 2). The multiplier for intensity of exertion is 3.0, and the multiplier for efforts per minute is 1.0. Their product is 3.0 (3.0 × 1.0) . If the exertion is applied for less than one second, the duration of exertion is less than 10%, the rating is 1, and the multiplier is 0.5. The product of all three multipliers is 1.5 (3.0 × 1.0 × 0.5)—a relatively low score that suggests minimal strain. By contrast, if the exertion is applied for nine seconds, the duration of exertion is 90%, the rating is 5, and the multiplier is 3.0. The revised product is 9.0 (3.0 × 1.0 × 3.0)—a moderately higher score that suggests greater strain. This implies that the latter circumstance puts significantly more strain on the body than the former—a reasonable finding since the job is approaching static effort despite the low intensity of exertion.

To extend the example further, consider a new job that requires a "near maximal" exertion every 10 seconds, then repeat the calculations above. For a brief duration of exertion (< 10%), the product of the intensity of exertion, efforts per minute, and duration of exertion multipliers is 6.5 (13.0 × 1.0 × 0.5)—a moderate amount of strain. However, if the duration of exertion is 90%, the product of the three multipliers is 39 (13.0 × 1.0 × 3.0), which is a very high score. Since maximal exertions can only be maintained for approximately six seconds, but the job requires nine seconds, this high score appropriately reflects the strain on the workers who perform it.

There are some jobs where an object, such as a tool, is constantly held in the hand, but the intensity of exertion required to use the tool is no greater than that required to hold it. One example is a Whizard knife. Even if the tool is used repeatedly for several trims per piece of meat, (e.g., it is possible to count actions per minute), the hand actually is performing static work if the tool is never set down. A special decision rule has been incorporated into the Strain Index methodology for this scenario. In this circumstance the duration of exertion rating is 5 and the multiplier is 3.0 according to the usual procedure. In addition, however, the efforts per minute multiplier is automatically set to 3.0. For a "light" exertion, the score is 9.0 (1.0 × 3.0 × 3.0). For a "near maximal" exertion, the score is 117.0 (13.0 × 3.0 × 3.0). The former is on the moderate strain range; the latter is extremely high.

Efforts Per Minute

Efforts per minute is the number of exertions per minute (e.g., repetitiveness) and is synonymous with frequency.

Efforts per minute are measured by counting the number of exertions that occur during a representative observation period (as described for determining the average exertional cycle time). In fact efforts per minute can be calculated from the exertional cycle time and vice versa. For example, a 30-second exertional cycle time is equivalent to two efforts per minute. The measured result is compared to the ranges in Table I and given the corresponding rating. The multipliers are identified from Table II.

The multiplier table values were derived using professional judgment to be consistent with the physiological and epidemiological considerations. To a degree, it is consistent with the rating scheme used by others.(8,9,63) Some exertions, even if forceful, may not pose significant strain if performed infrequently; however, increasing efforts per minute generally increases strain for a given intensity of exertion.

Consider another example. A job requires a one-second "hard" exertion twice per minute. The intensity of exertion rating is 3, and its multiplier is 6.0. The duration of exertion rating is 1, and its multiplier is 0.5. Since there are two efforts per minute, the rating is 1 and its multiplier is 0.5. The product of the three multipliers is 1.5 (6.0 × 0.5 × 0.5)—a relatively low score that implies minimal strain. The rationale for this result is that the relatively long recovery time between exertions minimizes strain on the body. If, however, this job was done every 4 seconds (15 efforts per minute), both the duration of exertion and the efforts per minute values change. The duration of exertion is now 25%, so its rating is 2 and its multiplier is 1.0. For efforts per minute the rating is 4 and the multiplier 2.0. The product of the three multipliers is now 12.0 (6.0 × 1.0 × 2.0)—a score that reflects almost eight times more strain.

Since a static exertion would be associated with very few efforts per minute (an apparent advantage according to the multipliers in Table II), a penalty for static work was incorporated into the Strain Index methodology by requiring that the efforts per minute multiplier be set to 3.0 when the percentage duration of exertion is essentially 100%.

Hand/Wrist Posture

Posture refers to the anatomical position of the wrist or hand relative to neutral position. It reflects the effects of posture on tensile stresses (reduced grip strength) and, when combined with intensity of exertion, reflects intrinsic compressive stresses to the contents of the flexor and extensor compartments about the wrist. The postural assessment protocol is based, to a degree, on ordinal rating schemes used by others.(20,80) An observer rates posture qualitatively rather than measuring it. The verbal anchors, while subjective, eliminate rigid cut-off criteria that cannot be currently justified and increase the ease of application of the model. A rating is assigned by comparing the verbal anchor to Table I. Differences among multiple job analysts should be resolved by consensus.

The multiplier table values were derived using professional judgment to be consistent with the physiological, biomechanical, and epidemiological considerations. Examination of Table II reveals that posture really has four relevant ratings. Postures that are "very good" or "good" are essentially neutral and have multipliers of 1.0 and, therefore, have no effect on the ultimate score. As hand or wrist postures progressively deviate beyond the neutral range to extremes, they are graded as "fair," "bad," and "very bad." The multipliers change accordingly. This rating scheme is consistent, to a degree, with those proposed by others.(8,9,20,80)

Consider another experiment. A job requires a "hard" exertion every six seconds. The duration of exertion is one second (17%). The product of these multipliers is 4.5 (3.0 × 1.5 × 1.0), a marginal score. If wrist posture is "very good" or "good," this result is not changed (i.e., there is no increased strain). If the wrist posture is "very bad," the rating is 5, the multiplier is 3.0, and the revised score is 13.5 (4.5 × 3.0). This is a moderately high score that reflects the additional strain on the body from applying the exertion in an extreme wrist posture. If the thumb were fully abducted but the wrist in neutral posture, the rating would still be "very bad" and the score unchanged. If the intensity of exertion was "light," the efforts per minute the same, and the hand or wrist posture "very bad," the score is 4.5 (1.0 × 1.5 × 1.0 × 3.0), a marginal score 67% lower than the previous example. The reason is that the low intensity of exertion implies low tensile load in the muscle-tendon unit, so that even if the associated tendon courses around a maximally flexed wrist, the intrinsic compressive load is lower.

Speed of Work

Speed of work estimates perceived pace of the task or job. It is included because of its modifying effects on exertions—i.e., maximal voluntary strength decreases and EMG amplitude increases with increasing speed.(59–61) In addition, it is suspected that a worker's muscles do not fully relax between high-speed, high-frequency exertions.

Speed of exertion is subjectively estimated by a job analyst or ergonomics team. Once a verbal anchor is selected, a rating is assigned according to Table I.

The multiplier table values were derived using professional judgment. As noted from inspection of Table II, there are really only three levels of rating for speed of work. "Very slow," "slow," and "fair" all have multipliers of 1.0. As a result, they have no effect on the final score. The term "very fast" applies when the observed worker either does not or barely manages to keep up with the required pace of the job. Normally, such workers are performing jobs with a relatively high rating for efforts per minute. They are overtly rushed and intently focused on the job. A "fast" speed of work is the intermediate choice. These workers are not overtly rushed, but rely on rapid deliberate actions to perform the job. They, too, likely perform jobs with high efforts-per-minute ratings and are focused on their work because of its pace.

Duration of Task Per Day

Duration of task per day reflects the total time that a task is performed per day. It attempts to incorporate the beneficial effects of task diversity such as job rotation (if the differing task is associated with reduced stresses) and the adverse effects of prolonged activity such as overtime. Duration of task per day is measured, expressed as hours, and assigned a rating according to Table I.

The multiplier table for duration of task per day was derived using professional judgment. It is designed to reflect no effect on strain if the task is performed for four to eight hours, a typical work schedule, but decreased strain with decreasing durations per day and increased strain with durations exceeding eight hours.

Consider a task that, based on consideration of intensity of exertion, duration of exertion, efforts per minute, wrist posture, and speed of work, has a score of 12.0. If the job requires performing that particular task for four to eight hours per day, the score is still 12.0. This is a moderately high score. If, however, the job is performed for less than one hour per day, the rating is 1 and the multiplier is 0.25. The revised score is 3.0, a fairly low score that reflects minimal strain.

The Strain Index Score

The Strain Index score (SI score) is the product of all six multipliers, as shown below by Equation 6, as demonstrated by examples in the task variable sections.

$$\text{Strain Index (SI)} = (\text{Intensity of Exertion Multiplier}) \times (\text{Duration of Exertion Multiplier}) \times (\text{Exertions per Minute Multiplier}) \times (\text{Posture Multiplier}) \times (\text{Speed of Work Multiplier}) \times (\text{Duration per Day Multiplier}). \quad (6)$$

INSTRUCTIONS

Application of the Strain Index involves (1) collecting data, (2) assigning rating values, (3) determining multipliers, (4) calculating the SI score, and (5) interpreting the results.

A job analyst or ergonomics team must collect data for all six task variables. Intensity of exertion, wrist posture, and speed of work are estimated using the verbal descriptors in Table I. The percentage duration of exertion per cycle, efforts per minute, and duration per day are based on measurements and counts. The datum for each variable is then compared to the appropriate column in Table I and assigned a rating (1, 2, 3, 4, or 5). Once all the variables have assigned ratings, the multipliers are determined from Table II. To calculate the SI score, the six multipliers are multiplied together. Appendix A is a user's guide summarizing these instructions and providing some guidelines (not strict decision rules) for the subjectively rated task variables.

Consider the following example (summarized in Table III). A job has the following characteristics: a ''somewhat hard'' estimated intensity of effort, a 60% percentage duration of exertion per cycle, 12 efforts per minute, ''fair'' wrist posture, ''fair'' speed of work, and duration per day of four to eight hours. Task variable ratings are determined from Table I, and the multipliers for each variable are then determined from Table II as follows:

- intensity of effort rating 2, multiplier of 3.0
- percentage duration of exertion rating 4, multiplier of 2.0
- efforts per minute rating 3, multiplier of 1.5
- wrist posture rating 3, multiplier of 1.5
- speed of work rating 3, a multiplier of 1.0
- duration per day rating 4, a multiplier of 1.0.

Multiplying all of these multipliers together yields an SI score of 13.5. The basis for interpreting this result is presented in the subsequent section; however, a job with an SI score in this range would be predicted to be associated with a moderate increased risk for distal upper extremity morbidity.

PRELIMINARY TESTING OF THE STRAIN INDEX

The Strain Index methodology was tested by the authors using a data set available from a previous study performed by the authors.[11] As a result, the authors were not blinded to the morbidity data. The Strain Index was not used to describe exposures in the original study. For the current analysis, each author independently re-evaluated the original videotapes, estimated or calculated the task variable exposure data, and assigned ratings. Informal comparison of the task variable ratings revealed some minor differences for the intensity of exertion and posture task variables on a few jobs. These were resolved by consensus. There were no discrepancies for the quantitative task variable ratings. A formal analysis of inter-rater variability was not done.

The details and definitions related to the morbidity assessment are in the original paper. The terms ''positive'' and ''negative'' describe the job categories. A positive job was observed to be associated with distal upper extremity morbidity, while a negative job was not. The distal upper extremity morbidity included specific disorders (epicondylitis, DeQuervain's tenosynovitis, trigger finger, trigger thumb, and CTS) that met well-defined case definitions. A second category of morbidity was called ''nonspecific disorders.'' This latter category included situations where the plant physician noted one or more symptoms, but did not report sufficient information to classify the condition as a specific disorder according to the case definitions. In this study, the symptoms were assumed to represent strain-related disorders of the muscle-tendon units. Incidence rates were expressed as total number of conditions per 100 workers per year.

For each job category, the incidence rate for total distal upper extremity disorders, the number of full-time equivalent workers assigned to the job during the 20-month observation period, the verbal descriptors chosen for the qualitative task variables, the measurements for the quantitative task variables, and the SI scores are listed in Table IV. There were 12 positive and 13 negative job categories.

Among positive job categories, the SI scores ranged from 4.5 to 81 with a mean of 29. Among negative job categories, the SI scores ranged from 0.5 to 4.5 with a mean of 2.3. The difference between the two means was statistically significant ($t = 4.05$; $df = 23$; $p < 0.01$).

If one selects a value of 5 as a threshold SI score to distinguish a safe from a hazardous job, then the current system correctly classifies all 13 negative jobs as safe and 11 of the 12 positive jobs as hazardous. These values correspond to a sensitivity of 0.92 ($11 \div 12$) and a specificity of 1.00 ($13 \div 13$). The single false prediction (Job No. 11) had an SI score of 4.5 and

TABLE III. An Example to Demonstrate the Procedure for Calculating the SI Score

	Intensity of Exertion	Duration of Exertion	Efforts/Minute	Posture	Speed of Work	Duration per Day
Exposure Data	somewhat hard	60%	12	fair	fair	4–8
Ratings	2	4	3	3	3	4
Multipliers	3.0	2.0	1.5	1.5	1.0	1.0

SI Score $= 3.0 \times 2.0 \times 1.5 \times 1.5 \times 1.0 \times 1.0 = 13.5$

TABLE IV. Incidence Rates and Exposure Data for the Preliminary Assessment, with Numerical Data for the Quantitative Task Variables and Assigned Ratings for the Qualitative Task Variables

Job No.	*FTE*^{A}	*Inc*^{B}	*Intensity of Exertion*	*Duration of Exertion*	*Efforts per Minute*	*Hand/ Wrist Posture*	*Speed of Exertion*	*Duration per Day*	*SI Score*
1	4	210	hard	100%	12^C	very good	very slow	4–8	54
2	3	160	hard	15%	13	fair	very slow	4–8	13.5
3	4	135	somewhat hard	15%	10	fair	very slow	4–8	7
4	6	130	somewhat hard	100%	10^C	fair	very fast	4–8	81
5	24	78	somewhat hard	39%	26	bad	very fast	4–8	54
6	4	75	near maximal	26%	9	fair	very slow	4–8	29
7	1	60	very hard	45%	4	fair	very slow	4–8	20
8	8	53	near maximal	3%	7	very good	very fast	2–4	10
9	2	30	hard	42%	9	very good	very slow	4–8	13.5
10	6	30	light	85%	47	bad	very fast	4–8	36
11	2	30	somewhat hard	36%	6	very good	very slow	4–8	4.5
12	12	25	near maximal	44%	5	fair	very slow	2–4	22
13	1	0	light	42%	32	very good	very slow	4–8	4.5
14	3	0	light	63%	7	very good	very slow	4–8	2
15	6	0	light	11%	8	very good	very slow	4–8	1
16	1	0	light	28%	23	fair	very slow	4–8	4.5
17	1	0	light	40%	39	very good	very slow	<1	4.5
18	2	0	light	27%	3	very good	very slow	4–8	0.5
19	2	0	light	16%	9	very good	very slow	4–8	1.5
20	2	0	light	48%	4	very good	very slow	<1	1.5
21	2	0	light	43%	2	very good	very slow	4–8	0.8
22	2	0	light	27%	13	very good	very slow	4–8	1.5
23	2	0	light	26%	14	very good	very slow	4–8	1.5
24	2	0	light	47%	17	very good	very slow	4–8	3
25	2	0	light	13%	27	very good	very slow	4–8	3

^{A} FTE = full time equivalent workers

^{B} Inc = incidence rate per 100 workers per year

^{C} Since the duration of exertion is 100%, the efforts per minute multiplier is automatically set to 3.0.

was associated with one nonspecific distal upper extremity symptom (left hand/wrist pain).

The relationship between SI score ranges and the occurrence of morbidity is summarized in Table V. The spectrum of disorders is relatively constant across jobs with SI scores between 5 and 60, with CTS representing less than 20% of the total morbidity. There was only one job with an SI score > 60, and CTS represented 38% of the morbidity. At this time, this increased percentage of CTS is considered secondary to small numbers rather than some correlation with an SI score > 60.

The relationship between SI score and mean incidence rate is shown in Figure 1. There was an increase in mean incidence rate for upper extremity disorders with an increase in SI score.

TABLE V. Analysis of Morbidity by SI Score Range

SI			*Number of Conditions*		
Score	*# Jobs*	*FTE*	*Elbow*	*Hand/Wrist*^{A}	*CTS*
<5	14	30	0	1	0
5–30	7	34	9	21	7
31–60	3	34	12	30	6
>60	1	6	3	5	5

^{A} All hand/wrist morbidity except CTS

SENSITIVITY ANALYSIS

To examine the effects of observer rating variation, a sensitivity analysis was conducted by promoting and demoting an individual task variable by one rating for all jobs, then counting the number of jobs that cross the tentative SI score threshold of 5.

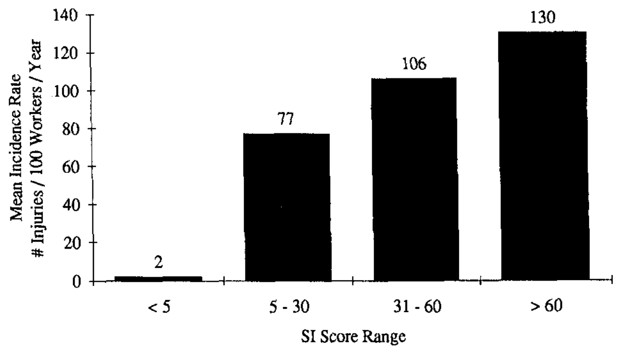

FIGURE 1. Mean incidence rate versus SI score

The model is relatively stable to such changes for all task variables except for one circumstance—promotion of intensity of exertion. In particular, the promotion of this task variable rating from 1 to 2 is associated with a shift of seven job categories to an SI score greater than 5. Six of these jobs were negative. To some degree, the verbal descriptors for intensity of exertion were selected to control for this effect. In addition, use of a consensus rating by an ergonomics team or committee may be helpful.

DISCUSSION

The Strain Index is an exposure assessment methodology based on multiplicative interactions among six task variables. In this regard, it is similar in concept to the recommended weight limit from the revised NIOSH *Guide for Manual Lifting*. The concept of multiplicative interactions among the task variables on risk for distal upper extremity morbidity is consistent with the findings of Silverstein et al.(6), Armstrong et al.(7), and Moore and Garg.(11) The first two studies reported that the combination of high forcefulness and high repetitiveness was the best predictor for the prevalence of CTS and tendon-related disorders. The third study reported a relationship between incidence rate and the product of intensity of exertion and percentage exertion time (100 − % recovery time). While the relationship between the risk of upper extremity disorders and task variables may not be exactly multiplicative, this appears to be a reasonable assumption that is consistent, coherent, and congruent with current knowledge.

Several task variables have been reported as potential or generic risk factors for distal upper extremity disorders. The Strain Index includes six task variables that were chosen by considering physiological, biomechanical, and epidemiological principles. However, it should be noted that the Strain Index is not based on any specific quantitative relationship between a task variable and some physiological, biomechanical, or epidemiological response.

Several different studies have either shown and/or proposed that intensity of exertion (force) and efforts per minute (repetitiveness) are among the most important task variables.(6–12,75) While there is lack of epidemiological support for posture as an independent risk factor, it has received almost universal attention. However, biomechanical and physiological considerations strongly suggest that posture is a relevant task variable based on its effects when combined with exertions.

Percentage duration of exertion has not only biomechanical and physiological implications, but also was found to be one of two risk factors that predicted the total incidence rate of distal upper extremity morbidity in one epidemiological study.(11) Marras et al. reported a relationship between risk of distal upper extremity disorders and speed of exertion.(81) The effects of duration of task per day appears not to have been studied, but is believed to be important and, therefore, was included in the Strain Index. As a result, the task variables included in the Strain Index methodology are consistent and congruent with existing knowledge.

The model does not include one task variable known to be related to distal upper extremity disorders, localized mechanical compression. In addition, it incorporates only one task variable related to work organization (duration of task per day). The methodology does not address other potentially significant factors, such as unaccustomed work. Otherwise, it is comprehensive. Regarding other potential risk factors, there is currently insufficient or contradictory data, which led to a decision not to incorporate them into the proposed Strain Index methodology. It is anticipated that the methodology will evolve as knowledge and experience increase.

Three of the six task variables (intensity of exertion, posture, and speed of exertion) have qualitative ratings and rely on the analyst's subjective judgment. In particular, intensity of exertion has a major impact on the SI score, but its rating is assigned subjectively. Thus, differences in ratings may arise from analyst bias, inexperience, and/or poor judgment. This is probably one of the weak points of the Strain Index. The user's guide (Appendix A) provides some additional guidelines for job analysts to use when rating these three task variables. It would be highly desirable to have some quantitative assessment of applied force or, even better, a quantitative measurement of tensile load. However, at present, such an approach appears to be impractical in an industrial setting due to technological and economic limitations. Force rating schemes proposed by Rodgers, Kilbolm et al., Keyserling et al., and others also have relied on subjective rating scales.(8–10,12) The use of multiple observers to develop a consensus rating may be desirable.

The proposed relationships between the task variable ratings and the multipliers are subject to criticism. There is a lack of data to determine exact relationships between the measured or estimated data for the task variables and the appropriate multipliers. To a significant extent, the proposed relationships are based on the authors' professional judgments. The authors relied heavily on thought experiments to derive the current multipliers—i.e., if a hypothetical job had particular task variable attributes, what would be the effects of changing one or more of them, and did the observed effect make sense. The application of the model to one data set shows its potential usefulness, but this area warrants future research. The authors anticipate that the model probably will need to be modified as it is applied to more industries and more quantitative epidemiological data become available. In the meantime, the ergonomists have the option to rely either on their own judgment or use a semiquantitative approach such as the one proposed, or a combination of both, recognizing that this is not perfect.

The proposed methodology should be subjected to further evaluation. It is currently unclear what level of ergonomics training or experience is necessary for a potential user to reliably understand and apply the Strain Index methodology. Inter-rater consistency and test-retest reliability have not been formally assessed. The predictive validity of the methodology should be further evaluated with a prospective longitudinal study or, if retrospective, in a study where the job analysts are blinded to the outcome measures. In addition, relationships between the Strain Index and nonhealth-related outcomes, such as absenteeism, employee turnover, quality, or job satisfaction, could be considered.

To date, the Strain Index methodology has been applied to 25 relatively simple jobs from a single plant associated with a single type of industry (pork processing). These jobs were characterized by stereotyped exertions performed, on average, 14 times per minute (range: 2 to 47). For these types of jobs, predicting risk based solely on intensity of exertion (greater than 1 or less than 1) also happens to correctly classify 24 of these 25 jobs and, therefore, could be considered simpler and equally accurate compared to using the Strain Index. However, the authors believe that such a method would not be equally applicable to jobs with fewer efforts per minute. To illustrate the limitation of this simplified model, a single exertion rated as "somewhat hard" and performed once per day would be considered hazardous.

At this time there is no proposed method for multiple task analysis. Currently, each task of a multitask job can be analyzed separately by considering duration of task per day. If the distal upper extremity is somewhat analogous to the low-back, it is suspected that the hazard potential of the job is primarily mediated by peak stresses, not time-weighted or some other averaged value.(82–84) As a result, an elevated Strain Index score for one task of a multitask job, if calculated with consideration of duration of task per day, might predict increased risk. Development of a multiple-task analysis methodology will require opportunities to evaluate such jobs and compare the results to the observed morbidity. It is a challenge for the future.

The following summarize the Strain Index methodology's foundations, limitations, and assumptions:

(1) It only applies to the distal upper extremity, but covers all relevant anatomical structures (all muscle-tendon units and the median nerve, in general).
(2) It predicts a spectrum of distal upper extremity morbidity, not particular disorders.
(3) It was designed to predict primarily disorders of the muscle-tendon units and CTS, not all distal upper extremity disorders—e.g., HAVS, osteoarthritis, ganglion cysts, ulnar nerve entrapment at the elbow, etc.
(4) It assesses jobs, not individual workers.
(5) It describes the exertional demands of a job. Mechanical compression should be considered separately.
(6) It relies on qualitative estimates for three task variables.
(7) The relationships between exposure data and multiplier values are not based on explicit mathematical relationships between task variables and some physiological, biomechanical, or epidemiological response.
(8) It has been tested only on a set of jobs already available to the authors. As a result, the authors were not blinded to the morbidity results. Longitudinal validation (preferably prospective) with job analysts blinded to the outcome measures is needed.
(9) The jobs used in the preliminary test were all from a single plant related to one industry. There was not a great deal of variation among some of the task variables.
(10) Test-retest reliability and inter-rater variability have not been formally evaluated.
(11) At this time, differences in task variable ratings should be resolved by consensus.
(12) Discriminating between a "light" versus a "somewhat hard" exertion appears to be critical. A more objective assessment method for intensity of exertion is highly desirable.
(13) The required training and experience to use the Strain Index effectively has not been determined.

Future studies should include multiple task analysis and evaluation of predictive validity for other outcomes (e.g., severity rate, turnover, etc.).

CONCLUSION

To date, exposure assessment to characterize jobs according to their potential for causing distal upper extremity disorders has relied on nonstandardized, subjective methods. While high extrinsic compression force (also called localized mechanical compression) is considered a significant risk factor for some disorders, its occurrence is relatively uncommon.(11,73) Rather, the physiological, biomechanical, and epidemiological literature suggest that the exertional aspects of a job are probably the most significant contributors to the occurrence of distal upper extremity disorders. The Strain Index is an exposure assessment tool that professionals and ergonomic teams can use to systematically evaluate the exertional demands of a job to predict increased risk of distal upper extremity disorder morbidity.

The six task variables in the Strain Index methodology were derived from physiological, biomechanical, and epidemiological principles. The methodology relies on multiplicative interactions between these task variables. Preliminary testing of the methodology's predictive validity suggests that it holds promise as a useful method to analyze jobs and predict hazard potential. Prospective users should understand the scientific foundation for the methodology, realize that they are relying on subjective estimates for some task variables, and clearly note the methodology's current limitations. As new research is published, and the model is used and evaluated by others and further validated using diverse jobs, it will likely undergo refinement.

REFERENCES

1. **Armstrong T.J.:** *An Ergonomics Guide to Carpal Tunnel Syndrome.* Cincinnati, OH: American Industrial Hygiene Association, 1983.
2. **Armstrong T.J. and Y. Lifshitz: Evaluation and design of jobs for control of cumulative trauma disorders. In** *Ergonomic Interventions to Prevent Musculoskeletal Injuries in Industry.* Chelsea, UK: Lewis Publishers Inc., 1987. pp. 73–85.
3. **Armstrong T.J., R.G. Radwin, D.J. Hansen, and K.W. Kennedy:** Repetitive trauma disorders: job evaluation and design. *Human Factors 28*:325–336 (1986).
4. **Silverstein B.A., L.J. Fine, and T.J. Armstrong:** Carpal tunnel syndrome: causes and a preventive strategy. *Semin. Occup. Med. 1*:213–221 (1986).
5. **Silverstein, B.A.:** "The Prevalence of Upper Extremity Cumulative Trauma Disorders in Industry." Ph.D. diss., University of Michigan, Ann Arbor, MI, 1985.

6. **Silverstein, B.A., L.J. Fine, and T.J. Armstrong:** Occupational factors and carpal tunnel syndrome. *Am. J. Ind. Med. 11*:343–358 (1987).
7. **Armstrong, T.J., L.J. Fine, S.A. Goldstein, Y.R. Lifshitz, and B.A. Silverstein:** Ergonomic considerations in hand and wrist tendinitis. *J. Hand Surg. 12A[2 Pt2]*:830–837 (1987).
8. **Rodgers, S.H.:** Job evaluation in worker fitness determination. *Occup. Med.: State of the Art Reviews 3(2)*:219–239 (1988).
9. **Rodgers, S.H.:** A functional job analysis technique. *Occup. Med.: State of the Art Reviews 7(4)*:679–711 (1992).
10. **Kilbom Å., L. Sperling, L. Wikström, R. Kadefors, and S. Dahlman:** A model for ergonomic evaluation of work with hand tools. In *Advances in Industrial Ergonomics and Safety V*. London: Taylor & Francis, 1993. pp. 629–636.
11. **Moore, J.S. and A. Garg:** Upper extremity disorders in a pork processing plant: relationships between job risk factors and morbidity. *Am. Ind. Hyg. Assoc. J. 55*:703–715 (1994).
12. **Keyserling, W.M., D.S. Stetson, B.A. Silverstein, and M.L. Brouver:** A checklist for evaluating risk factors associated with upper extremity cumulative trauma disorders. *Ergonomics 36(7)*:807–831 (1993).
13. **Kusnetz, S. and M.K. Hutchinson:** *A Guide to the Work-Relatedness of Disease.* [NIOSH Publication No. 79-116] Washington, D.C.: U.S. Department of Health, Education, and Welfare, 1979.
14. **Chaffin, D.B. and K.S. Park:** A longitudinal study of low-back pain associated with occupational weight lifting factors. *Am. Ind. Hyg. Assoc. J. 32*:513–525 (1973).
15. **Waters, T.R., V. Putz-Anderson, A. Garg, and L.J. Fine:** Revised NIOSH equation for the design and evaluation of manual handling tasks. *Ergonomics 36(7)*:749–776 (1993).
16. **Hadler, N.M.:** Cumulative trauma disorders. An iatrogenic concept. *J. Occup. Med. 32(1)*:38–41 (1990).
17. **Nathan, P.A., K.D. Meadows, and L.S. Doyle:** Occupation as a risk factor for impaired sensory conduction of the median nerve at the carpal tunnel. *J. Hand Surg. 13-B(2)*:167–170 (1988).
18. **Nathan, P.A., R.C. Keniston, L.D. Myers, and K.D. Meadows:** Longitudinal study of median nerve sensory conduction in industry. Relationship to age, genderm hand dominance, occupational hand use, and clinical diagnosis. *J. Hand Surg. 17A(5)*:850–857 (1992).
19. **Keyserling, W.M., T.J. Armstrong, and L. Punnett:** Ergonomic job analysis: a structured approach for identifying job risk factors associated with overexertion injuries and disorders. *Appl. Occup. Environ. Hyg. 6(5)*:353–363 (1991).
20. **Stetson D.S., W.M. Keyserling, B.A. Silverstein, and J.A. Leonard:** Observational analysis of the hand and wrist: a pilot study. *Appl. Occup. Environ. Hyg. 6(11)*:927–937 (1991).
21. *Dorland's Medical Dictionary*. Philadelphia: W.B. Saunders, 1992.
22. **Schneider, C.C.:** Stenosing fibrous tendovaginitis over radial styloid (DeQuervain). *Surg. Cynecol. Obstet. 64*:846–850 (1928).
23. **Diack, A.W. and J.P. Trommald:** DeQuervain's disease. *West J. Surg. 47*:629–633 (1939).
24. **Eichoff, E.:** Zur pathogenese der tendovaginitis stenosans. *Bruns' Beitr. Klin. Chir. 39*:746–755 (1927).
25. **Finkelstein, H.:** Stenosing tendovaginitis at the radial styloid. *J. Bone Joint Surg. 12*:509–540 (1930).
26. **Grifftiths, D.L.:** Tenosynovitis and tendovaginitis. *Br. Med. J. 1*:645–647 (1952).
27. **Patterson, D.C.:** DeQuervain's disease. *N. Engl. J. Med. 214*:101–102 (1936).
28. **Moore, J.S.:** Function, structure, and responses of components of the muscle-tendon unit. *Occup. Med.: State of the Art Reviews 7(4)*:713–740 (1992).
29. **Moore, J.S.:** Carpal tunnel syndrome. *Occup. Med.: State of the Art Reviews 7(4)*:741–763 (1992).
30. **Smith, E.M., D.A. Sonstegard, and W.H. Anderson:** Carpal tunnel syndrome: contribution of flexor tendons. *Arch. Phys. Med. Rehabil. 58*:379–385 (1977).
31. **Woltman, H.W.:** Neuritis associated with acromegaly. *Arch. Neurol. Psych. 45*:680–682 (1941).
32. **Cannon, B.W. and J.G. Love:** Tardy median palsy; median neuritis; median thenar neuritis amenable to surgery. *Surgery 20*:210–216 (1946).
33. **Watson-Jones, R.:** Léri's pleonosteosis, carpal tunnel compression of the median nerves and Morton's metatarsalgia. *J. Bone Joint Surg. 31B*:560–571 (1949).
34. **Michaelis, L.S.:** Stenosis of carpal tunnel, compression of median nerve and flexor tendon sheaths combined with rheumatoid arthritis elsewhere. *Proc. R. Soc. Med. 43*:414–417 (1950).
35. **Phalen, G.S. and J.I. Kendrick:** Compression neuropathy of the median nerve in the carpal tunnel. *J. Am. Med. Assoc. 164*:524–530 (1957).
36. **Lipscomb, P.R.:** Tenosynovitis of the hand and wrist: Carpal tunnel syndrome, DeQuervain's disease, trigger digit. *Clin. Orthop. 13*:164–180 (1959).
37. **Yamaguchi, Y.M., P.R. Lipscomb, and E.H. Soule:** Carpal tunnel syndrome. *Minn. Med. Jan.*:22–33 (1965).
38. **Phalen, G.S.:** The carpal-tunnel syndrome. *J. Bone Joint Surg. 48A*:211–228 (1966).
39. **Phalen, G.S.:** The carpal tunnel syndrome. *Clin. Orthop. 83*:29–40 (1972).
40. **Armstrong, T.J., W.A. Castelli, F.G. Evans, et al.:** Some histological changes in carpal tunnel contents and their biomechanical implications. *J. Occup. Med. 26*:197–201 (1984).
41. **Hymovich, L. and M. Lindholm:** Hand, wrist, and forearm injuries—the result of repetitive motions. *J. Occup. Med. 8*:574–577 (1966).
42. **Ferguson, D.:** Repetition injuries in process workers. *Med. J. Aust. 2*:408–412 (1971).
43. **Kuorinka, I. and P. Koskinen:** Occupational rheumatic diseases and upper limb pain in manual jobs in a light mechanical industry. *Scand. J. Work Environ. Health 5(Suppl. 3)*:39–47 (1979).
44. **Luopajarvi, T., I. Kuorinka, M. Virolainen, et al.:** Prevalence of tenosynovitis and other injuries of the upper extremities in repetitive work. *Scand. J. Work Environ. Health 5(Suppl. 3)*:48–55 (1979).
45. **Armstrong, T.J. and G.D. Langolf:** Ergonomics and occupational safety and health. In *Environmental and Occupational Medicine*. Boston: Little Brown & Company, 1982. pp. 765–784.
46. **Armstrong, T.J., J.A. Foulke, B.A. Joseph, et al.:** Investigation of cumulative trauma disorders in a poultry processing plant. *Am. Ind. Hyg. Assoc. J. 43*:103–116 (1982).
47. **Viikari-Juntura, E.:** Neck and upper limb disorders among slaughterhouse workers. *Scand. J. Work Environ. Health 9*:283–290 (1983).
48. **Moore, J.S. and A. Garg:** The spectrum of upper extremity disorders associated with hazardous work tasks. In *Advances in Industrial Ergonomics and Safety IV*. London: Taylor & Francis, 1992. pp. 723–730.
49. **Simonson, E.:** Introduction. In *Physiology of Work Capacity and Fatigue*. Springfield: Charles C. Thomas, 1971. p. xi.
50. **Chaffin, D.B.:** Localized muscle fatigue—definition and measurement. *J. Occup. Med. 15(4)*:346–354 (1973).
51. **Howard, N.J.:** Peritendinitis crepitans: a muscle-effort syndrome. *J. Bone Joint Surg. 19*:447–459 (1937).
52. **Rohmert, W.:** Physiologische grundlagen der erholungszeitbestimmung. *Zbl. Arb. Wiss. 19*:1–28 (1965).

53. **Mathiowetz, V., N. Kashman, G. Volland, K. Weber, M. Dowe, and S. Roger:** Grip and pinch strength: normative data for adults. *Arch. Phys. Med. Rehabil. 66*:69–74 (1985).
54. **SUNYAB-IE. 1982/1983:** Data from student laboratory projects for Industrial Engineering 436/536 (Physiological Basis for Human Factors) at the State University of New York at Buffalo, S.H. Rodgers, instructor. Cited in *Ergonomic Design for People at Work*, vol. 2, S.H. Rodgers, ed. New York: Van Nostrand Reinhold Co., 1986. p. 470.
55. **Swansen, A.B., I.B. Matev, and G. DeGroot:** The strength of the hand. *Bull. Prosthet. Res.* 1970. pp. 145–153.
56. **Imrahan, S.N.:** The influence of wrist position on different types of pinch strength. *Appl. Ergonom. 22(6)*:379–384 (1991).
57. **Fernandez, J.E., J.B. Dahalan, C.A. Halpern, and V. Viswanath:** The effect of wrist posture on pinch strength. In *Proceedings of the Human Factors Society 33rd Annual Meeting*. Denver: Human Factors Society, 1991. pp. 265–271.
58. **Fernandez, J.E., J.B. Dahalan, C.A. Halpern, and T.K. Fredericks:** The effect of deviated wrist posture on pinch strength for females. In *Advances in Industrial Ergonomics and Safety IV*, S. Kumar, ed. London: Taylor & Francis, 1992. pp. 693–700.
59. **Astrand, P-O. and K. Rodahl:** *Textbook of Work Physiology*, 3rd ed. New York: McGraw-Hill Book Co., 1986. pp. 43–45.
60. **Garg, A. and D. Beller:** One-handed dynamic pulling strength with special reference to speed, handle height and angle of pulling. *Int. J. Ind. Ergonom. 6*:231–240 (1990).
61. **Arndt, R.:** Work pace, stress, and cumulative trauma disorders. *J. Hand Surg. 12A[2 Pt 2]*:866–869 (1987).
62. **Hagberg, M.:** Muscular endurance and surface electromyogram in isometric and dynamic exercise. *J. Appl. Physiol. Respir. Environ. Exercise Physiol. 51(1)*:1–7 (1981).
63. **Lee, M.W.:** "A Stochastic Model of Muscle Fatigue in Frequent Strenuous Work Cycles." Ph.D. diss., University of Michigan, Ann Arbor, MI, 1979.
64. **Rohmert, W.:** Problems in determining rest allowances: part 1. Use of modern methods to evaluate stress and strain in static muscular work. *Appl. Ergonom. 4*:91–95, 1973.
65. **Haut, R.C. and R.W. Little:** A constitutive equation for collagen fiber. *J. Biomech. 5*:423–430 (1972).
66. **Goldstein, S.A., T.J. Armstrong, D.B. Chaffin, and L.S. Matthews:** Analysis of cumulative strain in tendon and tendon sheaths. *J. Biomech. 20*:1–6 (1987).
67. **Abrahams, M.:** Mechanical analysis of tendon in vitro: a preliminary report. *Med. Biol. Eng. 5*:433–443 (1967).
68. **Elliott, D.H.:** Structure and function of mammalian tendon. *Biol. Rev. 40*:392–421 (1965).
69. **Rigby, B.J., N. Harai, J.D. Spikes, et al.:** The mechanical properties of rat tail tendon. *J. Gen. Physiol. 43*:265–283 (1959).
70. **Hunt, J.R.:** The thenar and hypothenar types of neural atrophy of the hand. *Am. J. Med. Sci. 141*:224–241 (1911).
71. **Brouwer, B.:** The significance of phylogenetic and ontogenetic studies for the neuropathologist. *J. Nervous Mental Dis. 51(2)*:113–136 (1920).
72. **Harris, W.:** *Neuritis and Neuralgia.* London: Oxford University Press, 1926. pp. 93–98.
73. **Tichauer, E.:** Some aspects of stress on forearm and hand in industry. *J. Occup. Med. 8*:63–71 (1966).
74. **Armstrong, T.J. and D.B. Chaffin:** An investigation of relationship between displacement of the finger and wrist joint and the extrinsic finger flexor tendons. *J. Biomech. 11*:119–128 (1978).
75. **Putz-Anderson, V.:** *Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs.* London: Taylor & Francis, 1988.
76. **Borg, G.:** Psychophysical scaling with applications in physical work and the perception of exertion. *Scand. J. Work Environ. Health 16(Suppl. 1)*:55–58 (1979).
77. **Wangenheim, M., G. Gorg, and P. Holzmann:** A psychophysical study of work-related stress using observer ratings. *Upsala J. Med. Sci. 92*:1–17 (1987).
78. **Stevens, S.S.:** The psychophysics of sensory function. *Am. Sci. 48*:467–479 (1960).
79. **Borg, G.:** *Physical Performance and Perceived Exertion.* Copenhagen: Ejnar M. Munksgaard, 1962. p. 18.
80. **Armstrong, T.J., J.A. Foulke, B.S. Joseph, and S.A. Goldstein:** Investigation of cumulative trauma disorders in a poultry processing plant. *Am. Ind. Hyg. Assoc. J. 43*:103–116 (1982).
81. **Marras, W.S. and R.W. Schoenmarklin:** Wrist motions in industry. *Ergonomics 36(4)*:341–351 (1993).
82. **Herrin, G.D., M. Jaraiedi, and C.K. Anderson:** Prediction of overexertion injuries using biomechanical and psychophysical models. *Am. Ind. Hyg. Assoc. J. 47*:322–330 (1986).
83. **Ciriello, V.M., S.H. Snook, and G.J. Hughes:** Further studies of psychophysically determined maximum acceptable weights and forces. *Human Factors 35(1)*:175–186 (1993).
84. **Waters, T.R., V. Puttz-Anderson, and A. Garg:** *Applications Manual for the Revised NIOSH Lifting Equation.* [DHHS (NIOSH) Publication No. 94-110] Springfield, VA: National Technical Information Service, 1994.
85. **Barnes, R.M.:** *Motion and Time Study. Design and Measurement of Work.* New York: John Wiley & Sons, 1980.

APPENDIX A—A USER'S GUIDE FOR THE STRAIN INDEX

This guide describes how to perform the five steps associated with using the Strain Index. Page 1 describes the rating criteria and the measurements and calculations for the six task variables. The numerical ranges for assigning rating criteria for the subjective variables are only guidelines. Page 2 includes a table for entering your data and guides you through calculating an SI score.

Step 1: Data Collection

1. Intensity of Exertion is an estimate of the strength required to perform the task one time. Guidelines for assigning a rating criterion are presented in the following table. Write the most appropriate rating criterion into the data table.

Rating Criterion	*%MS*[A]	*Borg Scale*[B]	*Perceived Effort*
Light	<10%	≤2	barely noticeable or relaxed effort
Somewhat Hard	10%–29%	3	noticeable or definite effort
Hard	30%–49%	4–5	obvious effort; unchanged facial expression
Very Hard	50%–79%	6–7	substantial effort; changes facial expression
Near Maximal	≥80°	>7	uses shoulder or trunk to generate force

[A] Percentage of maximal strength

[B] Compared to the Borg CR-10 scale(76)

2. Duration of Exertion is calculated by measuring the duration of all exertions during an observation period, then dividing the measured duration of exertion by the total observation time and multiplying by 100.

$$\text{\% Duration of Exertion} = 100 \times \frac{\text{duration of all exertions (sec)}}{\text{total observation time (sec)}} = 100 \times \underline{\hspace{3em}} = \underline{\hspace{3em}}$$

3. Efforts per Minute are measured by counting the number of exertions that occur during an observation period, then dividing the number of exertions by the duration of the observation period, measured in minutes.

$$\text{Efforts per Minute} = \frac{\text{number of exertions}}{\text{total observation time (min)}} = \underline{\hspace{3em}} = \underline{\hspace{3em}}$$

4. Hand/Wrist Posture is an estimate of the position of the hand or wrist relative to neutral position. Guidelines for assigning a rating criterion are presented in the following table. Enter the result in the data table.

Rating Criterion	*Wrist Extension*[A]	*Wrist Flexion*[A]	*Ulnar Deviation*[A]	*Perceived Posture*
Very Good	0°–10°	0°–5°	0°–10°	perfectly neutral
Good	11°–25°	6°–15°	11°–15°	near neutral
Fair	26°–40°	16°–30°	16°–20°	nonneutral
Bad	41°–55°	31°–50°	21°–25°	marked deviation
Very Bad	>60°	>50°	>25°	near extreme

[A] Derived from data presented in Stetson et al.(20)

5. Speed of Work is an estimate of how fast the worker is working. Guidelines for assigning a rating criterion are presented in the following table. Enter the result in the data table.

Rating Criterion	*Compared to MTM-1*[A]	*Perceived Speed*
Very Slow	≤80%	extremely relaxed pace
Slow	81–90%	"taking one's own time"
Fair	91–100%	"normal" speed of motion
Fast	101–115%	rushed, but able to keep up
Very Fast	>115%	rushed and barely or unable to keep up

[A] The observed pace is divided by MTM-1's predicted pace and expressed as a percentage of predicted. See Barnes.(85)

6. Duration of Task per Day is either measured or obtained from plant personnel. Enter the result in the data table.

Step 2: Assign Ratings Values

Use the table below the find the rating values for each task variable. Select the appropriate entry for each variable, then find the corresponding rating value on the same row at the far left.

Rating Values	*Intensity of Exertion*	*Duration of Exertion*	*Efforts/Minute*	*Hand/Wrist Posture*	*Speed of Work*	*Duration per Day*
1	light	<10	<4	very good	very slow	≤1
2	somewhat hard	10–29	4–8	good	slow	1–2
3	hard	30–49	9–14	fair	fair	2–4
4	very hard	50–79	15–19	bad	fast	4–8
5	near maximal	≥80	≥20	very bad	very fast	≥8

Step 3: Determine the Multipliers

Rating Value	*Intensity of Exertion*	*Duration of Exertion*	*Efforts/Minute*	*Hand/Wrist Posture*	*Speed of Work*	*Duration per Day*
1	1	0.5	0.5	1.0	1.0	0.25
2	3	1.0	1.0	1.0	1.0	0.50
3	6	1.5	1.5	1.5	1.0	0.75
4	9	2.0	2.0	2.0	1.5	1.00
5	13	3.0[A]	3.0[A]	3.0	2.0	1.50

[A] If duration of exertion is 100%, then efforts/minute multiplier should be set to 3.0.

Enter Your Data Here:

	Intensity of Exertion	*Duration of Exertion*	*Efforts/Minute*	*Hand/Wrist Posture*	*Speed of Work*	*Duration per Day*
Step 1: Rating Criterion or Measured Result						
Step 2: Rating Value						
Step 3: Multiplier						

Step 4: Calculate the SI Score

Insert the multiplier values for each of the six task variables into the spaces below, then multiply them all together.

Intensity of Exertion	×	Duration of Exertion	×	Efforts per Minute	×	Hand/Wrist Posture	×	Speed of Work	×	Duration of Task	=	SI Score
________	×	________	×	________	×	________	×	______	×	______	=	____

Step 5: Interpret the Result

Preliminary testing has revealed that jobs associated with distal upper extremity disorders had SI Scores greater than 5. SI Scores less than or equal to 3 are probably safe. SI Scores greater than or equal to 7 are probably hazardous. The Strain Index does not consider stresses related to localized mechanical compression. This risk factor should be considered separately.