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The Revised Strain Index: an improved upper extremity exposure assessment model

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ABSTRACT

The Revised Strain Index (RSI) is a distal upper extremity (DUE) physical exposure assessment model based on: intensity of exertion, frequency of exertion, duration per exertion, hand/wrist posture and duration of task per day. The RSI improves upon the 1995 Strain Index (SI) by using continuous rather than categorical multipliers, and replacing duty cycle with duration per exertion. In a simulation of 13,944 tasks, the RSI and 1995 SI showed good agreement in risk predictions for 1995 SI scores ≤3 (safe) and >13.5 (hazardous). For tasks with 1995 SI scores of >3 and ≤13.5, the two models showed marked disagreement, with the RSI providing much greater discriminations between 'safe' and 'hazardous' tasks for various combinations of force, repetition and duty cycle. We believe the RSI is a substantially improved model that will be useful for DUE task analysis, intervention and design.

Practitioner Summary: RSI is a substantial improvement over the 1995 SI. It should be a valuable tool for designing and analysing tasks to determine risk of musculoskeletal injuries. RSI is applicable to a wide variety of tasks including very low force and very high repetition tasks such as keyboard use.

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Introduction

Several studies have reported that exposures to high force, high repetition, non-neutral hand/wrist posture and/or hand/arm vibrations from vibrating hand tools are associated with increased risk of distal upper extremity (DUE) symptoms and or musculoskeletal disorders (MSDs) (Moore and Garg 1995; Bernard 1997; Mani and Gerr 2000; Moore, Rucker, and Knox 2001; Garg and Kapellusch 2011; Harris-Adamson et al. 2011, 2015). The literature suggests that those jobs requiring a combination of high force and high repetition have a greater risk for DUE MSDs than those jobs requiring exposure to either high force or high repetition alone (Armstrong et al. 1987; Silverstein, Fine, and Armstrong 1987; Chiang et al. 1993; Osorio et al. 1994; Moore, Rucker, and Knox 2001; Melchior et al. 2006; Garg and Kapellusch 2011; Gallagher and Heberger 2013; Harris-Adamson et al. 2015). In a recent study, Harris-Adamson et al. (2015) reported that the per cent time spent in forceful hand exertions was associated with an increased risk of incident carpal tunnel syndrome in a dose-dependent pattern, consistent with the findings of Moore and Garg (1994). Regarding exposure to force, repetition and posture, it appears that these risk factors interact in a multiplicative manner.

Several job analysis methods have been proposed to evaluate the combinations of job physical factors that expose a worker to an increased risk of DUE MSDs (Garg and Kapellusch 2011). In North America, one of the commonly used quantitative job analysis methods to measure DUE job physical exposures (Dempsey, McGorry, and Maynard 2005) is the Strain Index (SI) (Moore and Garg 1995). In this current paper, this original version of the SI is referred to as the '1995 SI' to avoid confusion between it and this proposed revision, which is called the 'Revised Strain Index' (RSI). The 1995 SI provides summary measures of risk based on combinations of six job physical factors: intensity of exertion, efforts per minute, duration of exertion (as a percentage of cycle time), hand/wrist posture, speed of work and duration of task per day (hours). The 1995 SI was developed based on principles derived from physiology, biomechanics and epidemiology (Moore and Garg 1995). Several epidemiological studies have shown relationships between the 1995 SI score and risk of DUE MSDs (Moore and Garg 1995; Bovenzi and Hulshof 1998; Knox and Moore 2001; Moore, Rucker, and Knox 2001; Rucker and Moore 2002; Drinkaus et al. 2003; Drinkaus et al. 2005; Moore et al. 2006; Silverstein et al. 2006; Spielholz et al. 2008; Harris-Adamson et al. 2011; Garg

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et al. 2012; Garg et al. 2014; Kapellusch et al. 2014; Meyers, Gerr, and Fethke 2014).

While the 1995 SI has served well in determining risk of DUE MSDs, it has certain limitations. These include: (i) use of categorical variables and their corresponding multipliers leading to very different SI scores with a one unit change in intensity of exertion, number of exertions or duty cycle, at their cut points, (ii) lack of discriminative power between very low and up to moderate intensity of force even though many exertions fall into this force range (i.e. % maximum voluntary contraction, %MVC = 1–29% range, can only be rated as 'light' or 'somewhat hard') (Garg et al. 2012; Harris-Adamson et al. 2015), (iii) the efforts per minute multiplier is capped at 20 exertions per minute and there is some concern that tasks with >20 efforts per minute may not be appropriately penalised (Garg et al. 2012) and (iv) use of duty cycle – which is confounded with efforts per minute – to account for duration of exertion. Regarding duration per exertion, psychophysical studies suggest that, given two tasks having the same % MVC and duty cycle, the one with a lower frequency of exertion and a higher duration per exertion may be more fatiguing than the corresponding task with higher frequency and lower duration per exertion (Dahalan and Fernandez 1993; Stephens 2006).

To address these limitations, we propose the RSI. The RSI reflects recent research findings since the development of the 1995 SI and addresses the aforementioned limitations of the 1995 SI.

The RSI

The RSI is conceptually similar to the 1995 SI but with three key differences, the RSI: (i) omits speed of work, (ii) relies on duration per exertion rather than duty cycle and (iii) uses continuous variables and multipliers rather than categorical variables and multipliers. Regarding speed of work, our experience over the last 20 years has shown that it is rarely an important issue (Garg et al. 2012) and, to a certain extent, is accounted for in the efforts per minute and duration per exertion variables. Thus, the RSI is a five variable model that includes: (i) intensity of exertion (force), (ii) efforts per minute (frequency), (iii) duration per exertion, (iv) hand/wrist posture (wrist flexion or extension) and (v) duration of task per day.

Out of these five variables, intensity of exertion, efforts per minute and hours of exposure per day have exactly the same operational definitions as those in the 1995 SI (though the corresponding multipliers are different). For the hand/wrist posture variable, a distinction is made whether the gripping/pinching force is applied in wrist extension or flexion. This is because both grip and wrist strengths are significantly lower in wrist flexion than in extension (Cykana 2002; Garg, Cykana, and Hegmann 2003; Shih and Ou 2005; Seo, Armstrong, and Young 2010) and psychophysical studies show that maximum acceptable frequency is lower in wrist flexion than in neutral hand/wrist posture or wrist extension (Kim and Fernandez 1993; Davis and Fernandez 1994; Marley and Fernandez 1995; Klein and Fernandez 1997).

We replaced duty cycle with duration per exertion. While these two variables are correlated – duty cycle (per minute) is equal to the average duration per exertion multiplied by the efforts per minute – the duty cycle does not differentiate between two tasks having the same duty cycle but different exertion durations. Tasks with low-frequency, long-duration exertions are generally expected to produce greater static muscle loading and thus may result in greater stresses than tasks with high-frequency, short-duration exertions, even if the duty cycles for the tasks are identical.

For example, consider two tasks: task 'A' with 2 exertions per minute of 25s each and task 'B' with 25 exertions per minute of 2s each. Both tasks have the same duty cycle (83%). Task 'A' has more static loading and less repetition while task 'B' has more repetition and less static loading. The 1995 SI score for task 'B' is 6 times higher than the score for task 'A'; however, due to static loading of muscles, the risk associated with task 'A' may be the same or higher than that of task 'B'. Thus, for task analysis and design, we believe that the combination of frequency of exertion and duration per exertion can separately address static muscular load and high repetition concerns and is, therefore, superior to the combination of frequency of exertion and duty cycle.

RSI variables

The following is a brief description of the five variables in the RSI.

Intensity of exertion (I)

Intensity of exertion represents the force requirements of a task. It reflects the magnitude of muscular effort required to perform the task and is defined as the percentage of maximum strength (%MVC) required to perform the task once.

For applications in the field, %MVC can be estimated using the Borg CR-10 perceived exertion scale (Borg 1982). We have conducted laboratory studies to quantify the relationship between the %MVC and the Borg CR-10 rating and these studies have consistently found a linear relationship between %MVC and Borg CR-10 rating except at the very low and very high extremes of %MVC (data not shown). Thus, for practical applications, %MVC can be estimated by multiplying Borg CR-10 rating by 10.

When feasible, we recommend that a team of analysts perform the task themselves – to experience the task's force requirements – prior to determining Borg CR-10 ratings. Rating differences between analysts should be resolved by consensus. When analysts are unable to perform the task themselves, we recommend direct observation of one or more workers rather than relying on videotape alone. Similarly, while Borg CR-10 ratings from multiple analysts are desirable, a single analyst may rate the task when multiple analysts are not available.

Efforts per minute (E)

An effort is defined as a direct application of force through the hand and usually occurs with prehension (e.g. holding an object or using a tool), but also includes direct applications of force with the hand such as typing, pressing controls or pushing objects. Efforts per minute, which is synonymous with frequency of exertion, is a measure of repetitiveness and is defined as the number of exertions per minute. To determine efforts per minute, an analyst or team should observe the task (or a representative videotape of it) for several complete task cycles. For tasks with very large cycle times (e.g. more than 10 min), the task should be observed for a sufficient period of time to obtain a reasonable representation of the task requirements. Efforts per minute is calculated by counting the number of exertions that occur during a representative observation period and dividing the sum by the observation period duration in minutes. The observation period can be measured with a stopwatch. The number of exertions can be counted using a counter.

Duration per exertion (D)

Duration per exertion is the average time (measured in seconds) that an exertion is applied. The total exertion time (i.e. total time spent applying force) during an observation period can be measured with a stopwatch. The average duration per exertion can be calculated by dividing the total exertion time (seconds) by the number of exertions counted during the observation period.

Users of the RSI are cautioned that certain combinations of efforts/minute and duration per exertion cannot be completed within one minute and the user should make sure that the computed duty cycle does not exceed 100%.

Hand/wrist posture (P)

Posture refers to the anatomical position of the hand/wrist relative to anatomical neutral. A distinction is made whether the wrist is in neutral, flexion or extension. Analysts should observe the task and determine: (i) whether the wrist is in flexion or extension when applying force, and (ii) the amount of flexion or extension (degrees of deviation from anatomical neutral) when applying force. When different hand/wrist postures are observed, the regularly occurring posture that requires the greatest %MVC should be used.

Duration of task per day (H)

Duration of task per day is the total time that a task is performed per day. It reflects the adverse effects of prolonged activity, including overtime. Duration of task per day is measured in hours.

RSI multipliers

Currently, there are not sufficient data to specify dose–response relationships between these five individual task variables and the risk of DUE MSDs. Therefore, like the 1995 SI, professional judgement was used to derive multiplier values for the RSI that are consistent with psychophysical, physiological, biomechanical and epidemiological considerations. RSI multipliers are based on the principle that increasing values of intensity of exertion (force), duration of exertion, efforts per minute, flexion/extension of the wrist and/or duration of task per day increases strain on the body. These multipliers also reflect observations such as, 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. An examination of data recently collected for epidemiological studies (Garg et al. 2012; Kapellusch et al. 2014; Harris-Adamson et al. 2015) suggests that very low %MVC exertions performed at high frequency but with very short duration of exertions (e.g. keying, wiring, pipetting) can be performed without increased risk of adverse health effects. On the contrary, tasks involving very high %MVC, low frequency and long duration of exertion are associated with an increased risk of DUE MSDs. The RSI attempts to incorporate these observations with new intensity of exertion, duration per exertion and efforts per minute multipliers. Figure 1 shows how RSI and 1995 SI multipliers compare.

For the intensity of exertion multiplier, a non-linear relationship was selected because the physiological, biomechanical and epidemiological principles, as well as psychophysical theory, suggest a nonlinear relationship between intensity of exertion and manifestation of strain. In the 1995 SI, the intensity of exertion multiplier was applied force rating (on a scale of 1–5) raised to the power 1.6. Borg and Kaijser (2006) later suggested an exponent of 1.2 instead of 1.6 (sd = 0.4). Data collected in our laboratories (not reported here), as well an examination of psychophysical studies on maximum acceptable frequencies, suggest that the exponent is approximately 1.2 at lower %MVCs and seems to increase as a function of %MVC at higher %MVCs. Further, in psychophysical

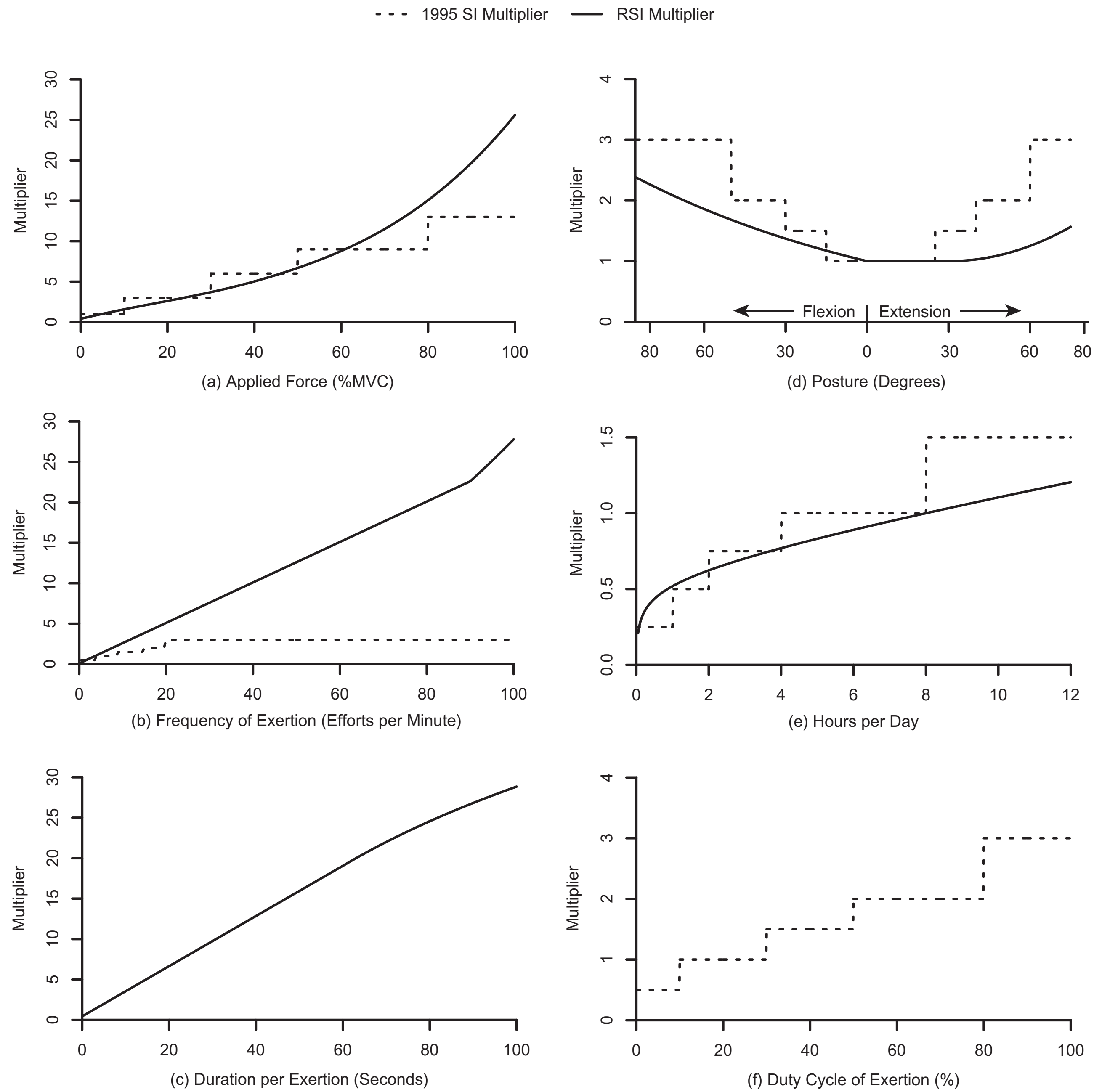

Figure 1. Comparison of RSI and 1995 SI multipliers.

studies, it appears that subjects tend to underestimate maximum acceptable frequency at low %MVC and overestimate maximum acceptable frequency at higher %MVC. The RSI intensity of exertion multiplier reflects these observations (Figure 1(a)).

In the 1995 SI, the efforts per minute multiplier had a linear relationship with the efforts/min. In the RSI, the efforts per minute multiplier also has a linear relationship with frequency of exertion up to 90 efforts/min, and then it increases non-linearly. However, the efforts per minute multiplier in the RSI is assigned a greater weight than the efforts per minute multiplier in the 1995 SI (Figure 1(b)). This increased penalty from the efforts per minute multiplier is offset by the duration per exertion multiplier, particularly for exertions of 1s or less (see below).

In the 1995 SI, the duration of exertion multiplier has a linear relationship with the duty cycle (% duration of exertion) (Figure 1(f)). Similarly, in the RSI, the duration per exertion multiplier also has a linear relationship with the duration per exertion up to an exertion of 60s. Beyond 60s, the multiplier gradually reduces the rate of increase in penalty (Figure 1(c)). However, unlike the 1995 SI, which penalises duty cycle, the RSI penalises duration of exertion and efforts per minute independently. For example, consider a task with 30 exertions per minute of 0.8s each (40% duty cycle). The 1995 SI penalises this task *both* for frequency of exertion and for duration of exertion (duty cycle), resulting in a double penalty. Conversely, because the duration of each exertion is very short, the RSI does not penalise for duration per exertion (i.e. the multiplier is ≤ 1.0) but it does penalise for frequency of exertion.

Recent prospective cohort studies on DUE MSDs suggest that hand/wrist posture is likely not an independent risk factor for DUE MSDs (Silverstein et al. 2010; Harris-Adamson et al. 2011; Burt et al. 2011; Garg et al. 2012; Garg et al. 2014; Fan et al. 2015; Harris-Adamson et al. 2015). Similarly, the American Conference of Governmental Industrial Hygienists (2002) also does not include hand/wrist posture as a risk factor in the Threshold Limit Value for Hand Activity Level (TLV for HAL). However, biomechanical and physiological considerations suggest that the hand/wrist posture is a relevant risk factor when combined with forceful exertions. Consistent with the 1995 SI construct, we have kept the hand/wrist posture as a variable; however, we have reduced the penalty, especially for wrist extension (Figure 1(d)).

In the 1995 SI, the duration of task per day multiplier was based on professional judgement. It had multiplier values of 0.25 and 1.5 for ≤1 and >8 h of task exposure per day, respectively. Data collected in our laboratories suggest that the 0.25 multiplier for a task duration of up to 1 h is too low. For example, we found that a 50% MVC, 6 efforts per minute task with 6s duration per exertion could be performed for less than 15 min; far short of 1 h. Similar findings were reported by Byström and Kilbom (1990), Dahalan and Fernandez (1993), Klein and Fernandez (1997) and Stephens (2006), and have shown that subjects were unable to continue with exertions requiring high %MVC (e.g. >50%) and long duration of exertion (e.g. ≥ 5s per exertion), or that the maximum acceptable frequencies were fairly low and resulted in very high perceived exertion ratings. Therefore, the RSI duration of task per day multiplier rapidly increases from about 0.2 at 3 min of task duration to approximately 0.5 at 1 h of task duration (Figure 1(e)). Similarly, recent epidemiological studies (cited under hand/wrist posture) did not find that those workers exposed for 10 or 12 h per day were at significantly higher risk of DUE MSDs than those workers exposed to the same biomechanical stressors (measured using either the TLV for HAL or the SI) for 8 h per day. However, the acceptable level of physical exposure for 12 h per day logically should be lower than that for 8 h. While there are no studies on hand intensive work, based on a psychophysical study for manual materials handling tasks Mital (1983) reported an about 8% decrease in acceptable workload when the duration of exposure was increased from 8 to 12 h. Thus, at 12 h per day the RSI multiplier is 1.2 as compared to the 1995 SI multiplier of 1.5 (Figure 1(e)). A word of caution is that the proposed hours per day multiplier for extended work shift (e.g. 1.2 for 12 h of exposure per day) may not be sufficiently protective, depending upon number of days per week a worker is exposed, work–rest patterns, and the nature of biomechanical and physiological stressors and changes in those stressors during an extended work shift.

The RSI score

The RSI score is the product of five multipliers, as shown below by Equation (1).

$$\mathrm{RSI} = \mathrm{IM} \cdot \mathrm{EM} \cdot \mathrm{DM} \cdot \mathrm{PM} \cdot \mathrm{HM} \tag{1}$$

Where,

$$\mathrm{IM} = \begin{cases} 30.00 \cdot I^3 - 15.60 \cdot I^2 + 13.00 \cdot I + 0.40, 0.0 < I \le 0.4 \\ 36.00 \cdot I^3 - 33.30 \cdot I^2 + 24.77 \cdot I - 1.86, 0.4 < I \le 1.0 \end{cases} \tag{2}$$

$$\mathrm{EM} = \begin{cases} 0.10 + 0.25 \cdot E, E \le 90/m \\ 0.00334 \cdot E^{1.96}, E > 90/m \end{cases} \tag{3}$$

$$\mathrm{DM} = \begin{cases} 0.45 + 0.31 \cdot D, D \le 60s \\ 19.17 \cdot \log_e(D) - 59.44, D > 60s \end{cases} \tag{4}$$

$$\mathrm{PM} = \begin{cases} 1.2 \cdot e^{(0.009 \cdot P)} - 0.2, \quad P = \text{Degrees of wrist flexion} \\ 1.0, \quad P \le 30 \text{ Degrees of wrist extension} \\ 1.0 + 0.00028 \cdot (P-30)^2, \quad p > 30 \text{ Degrees of wrist extension} \end{cases} \tag{5}$$

$$\mathrm{HM} = \begin{cases} 0.20, H \le 0.05\ h \\ 0.042 \cdot H + 0.090 \cdot \log_e(H) + 0.477, H > 0.05\ h \end{cases} \tag{6}$$

IM = Intensity of exertion (force) multiplier.
EM = Exertions per minute (frequency) multiplier.
DM = Duration per exertion multiplier.

PM = Hand/wrist posture multiplier.

HM = Duration of task per day multiplier.

I = Intensity of exertion (%MVC expressed numerically from 0 to 1.0, or Borg CR-10 rating divided by 10.0).

E = Efforts/min (count of exertions divided by total observation time in minutes).

D = Duration per exertion (seconds).

P = Hand/wrist posture (degrees from anatomical neutral).

H = Duration of task per day (hours).

RSI is designed such that a score of up to 10.0 is considered 'safe' and a score of >10.0 is considered 'hazardous'. Precise limits will need to be set based on findings from future epidemiological studies as well as government and/or employer policies for risk tolerance.

Comparison of the 1995 SI and the RSI

To compare the performance of the RSI with the 1995 SI, we simulated tasks with different combinations of intensity of exertion (I), efforts per minute (E) and duration per exertion (D). For simplicity, we assumed neutral hand/wrist posture (P) and that all tasks were performed for 8 h per day (H). The intensity of exertion (I) values were 1, 5% and then in increments of 5 up to 100% of MVC. Efforts per minute (E) ranged from 0.2 to 120 efforts/min, and the values were 0.2, 0.5, 1.0 to 20.0 in increments of 1.0, and 25.0–120.0 increments of 5.0. Duration per exertion (D) included 0.5s–1.0s in increments of 0.1s, 1.2s–3.0s in increments of 0.2s, 3.5s–10.0s in increments of 0.5s, 12.0s–20.0s in increments of 2.0s and then 25.0s–60.0s in increments of 5.0s. Based on the above parameters, the

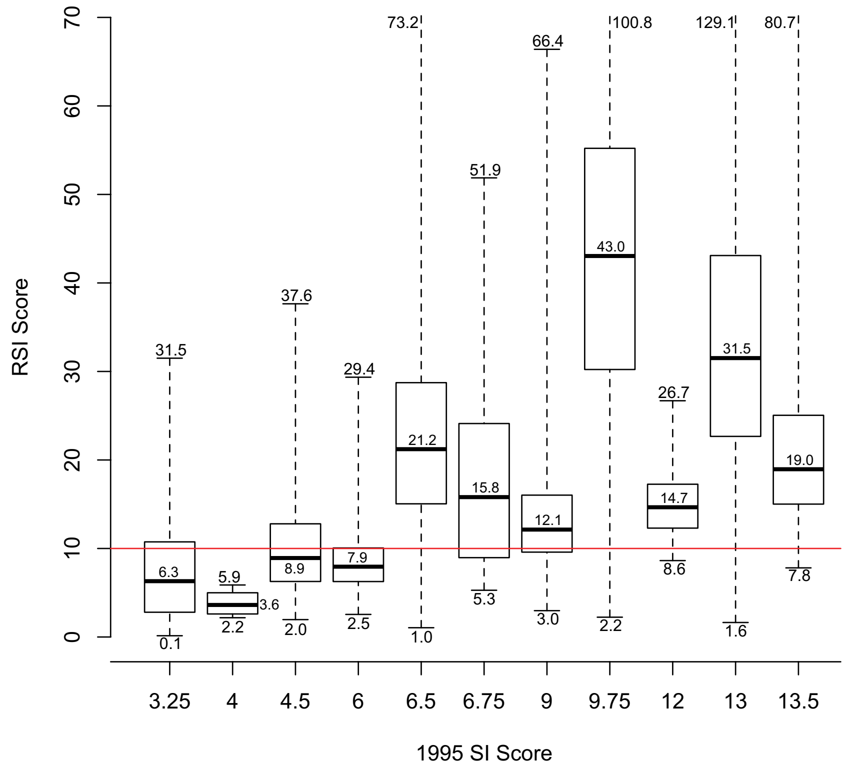

Figure 2. Box-and-whisker plot showing the median, interquartile range and overall range of RSI scores for those combinations of intensity of exertion, efforts per minute, and duration of exertion resulting in a discrete 1995 SI score > 3.0 and ≤ 13.5.

Table 1. Comparison of RSI and 1995 SI scores and risk classifications based on simulation of N = 13,944 tasks.

	1995 Strain Index (SI) score range			
	SI <= 3.0	3.0 < SI <= 6.1	6.1 < SI <= 13.5	SI > 13.5
	'Low' Risk	'Low' Risk	'High' Risk	'High' Risk
Number of simulated tasks (*N*)	3,244	2,086	3,141	5,473
RSI: Mean score	3.0	8.7	20.8	64.0
RSI: Standard deviation	2.4	5.2	14.8	57.4
RSI: Range	0.1 – 16.6	0.1 – 37.5	1.1 – 129.1	2.5 – 615.3
RSI: Median	2.4	7.8	16.8	47.8
RSI: Inter-quartile range	1.2 - 4.2	5.3 – 11.2	11.6 – 25.9	28.1 – 80.7
Risk classification, % agreement	98.2%	67.5%	82.9%	94.4%

Table 2. Summary of RSI scores for varying combinations of intensity, frequency and duty cycle of exertion that result in a 1995 SI score of 4.5 (N = 845 of 13,944 simulated tasks).

%MVC	1995 SI IM	Exertions per minute	1995 SI FM	Duty cycle (%)	1995 SI DM	1995 SI score	RSI score range
<10	1.0	9–14	1.5	80–100	3.0	4.5	2.7 – 6.3
<10	1.0	>20	3.0	30–49	1.5	4.5	2.0 – 8.5
10–29	3.0	4–8	1.0	30–49	1.5	4.5	4.3 – 10.1
10–29	3.0	9–14	1.5	10–29	1.0	4.5	3.3 – 9.3
30–49	6.0	0–4	0.5	30–49	1.5	4.5	7.2 – 22.9
30–49	6.0	9–14	1.5	<10	0.5	4.5	5.3 – 10.0
50–79	9.0	0–4	0.5	10–29	1.0	4.5	5.4 – 37.6
50–79	9.0	4–8	1.0	<10	0.5	4.5	4.5 – 18.5

simulation produced 37,926 tasks. After stripping off those tasks with computed duty cycle >100%, the simulation produced 13,944 tasks that were theoretically feasible. We acknowledge that some of these 13,944 tasks were likely not biologically feasible.

The 1995 SI and RSI scores for the 13,944 tasks were computed using the 1995 SI model (Moore and Garg 1995) and Equation (1), respectively. The 1995 SI model resulted in 35 discrete 1995 SI scores, due to the categorical nature of the 1995 SI multipliers; whereas, each unique combination of intensity of exertion, efforts per minute and duration of exertion resulted in a unique RSI score. The r^2 between the scores of the two models was 0.62. Using the 1995 SI, the tasks were classified either as 'safe' (1995 SI score ≤ 6.1) or 'hazardous' (1995 SI score >6.1) (Moore et al. 2006). Similarly, using the RSI, the tasks were classified either as 'safe' (RSI score ≤ 10.0) or 'hazardous' (RSI score >10.0). Table 1 summarises the relevant statistics for these tasks as well as hazard classification of these tasks using the 1995 SI and RSI models.

Both the models had very good agreement in classifying the tasks as 'safe' when the 1995 SI score was ≤3.0 and as 'hazardous' when the 1995 SI score was >13.5 (Table 1). For 1995 SI scores >3.0 and ≤13.5, the two models showed marked disagreement in classifying the jobs as 'safe' vs. 'hazardous'. To further highlight the differences between the two models, Figure 2 provides a box and whisker plot showing the median, interquartile range and overall range of RSI scores for those combinations of intensity of exertion, efforts per minute and duration of exertion resulting in a discrete 1995 SI score >3.0 and ≤13.5. For example, combinations of intensity of exertion, efforts per minute and duration of exertion that resulted in a 1995 SI score of 4.5 had RSI scores ranging from 2.0 to 37.6 with a median of 8.9 (Figure 2). For 1995 SI scores >3.0 and ≤6.1 (classified as 'safe' tasks by the 1995 SI), nearly one-in-three tasks (32.5%) were classified as 'hazardous' using the RSI model (Table 1 and Figure 2). Similarly, for tasks with 1995 SI scores >6.1 and ≤13.5 (classified as 'hazardous' tasks by the 1995 SI), about one-in-six tasks (17.1%) were classified as 'safe' using the RSI model (Table 1 and Figure 2).

There are three noteworthy observations from Figure 2. First, the two models seem to be in full agreement (safe vs. hazardous) for the 1995 SI score of 4.0, but not for the other 1995 SI scores between 3.25 and 13.5. Second, while both the RSI and 1995 SI models imply that increasing scores represent increased risk for DUE MSDs, the two models showed somewhat different risk prediction patterns. For example, the RSI model suggests that the DUE MSD risk is higher at 1995 SI score of 9.75 than at 1995 SI scores of 12.0, 13.0 and 13.5 (where median RSI scores are 43, 14.7, and 19.0, respectively). Similarly, the median RSI scores decreased from 21.2 to 15.8 to 12.1 as the 1995 SI scores increased from 6.5, 6.75 to 9.0. This phenomenon occurs primarily due to the categorical nature of the 1995 SI multipliers. For example, the 1995 SI score of 6.5 can only be obtained when the intensity of exertion rating is 5 (i.e. %MVC >80) resulting in an intensity of exertion multiplier of 13. Conversely, the 1995 SI score of 9.0 can never be obtained with an intensity of exertion multiplier of 13. Thus, the relatively increased penalty associated with the RSI intensity of exertion multiplier at very high force levels causes RSI scores to be generally higher at the 1995 SI score of 6.5 than at 6.75 and 9.0. These types of differences in risk prediction patterns between the two models were observed throughout the full range of 1995 SI scores. Last, certain combinations of intensity of exertion, efforts per minute and duration of exertion resulted in the same 1995 SI score, while the RSI scores showed a large variation (often ranging from 'safe' to extremely 'hazardous' classifications), thus the RSI appears to provide much more discrimination of estimated risk for these three variable combinations. For example, within the simulated tasks, eight different combinations of 1995 SI multiplier categories – with corresponding intensity of exertion ranging from 1 to 75% MVC, 0.2–55 efforts/min and duty cycle ranging from 3 to 98% – produced a 1995 SI score of 4.5 (Table 2), while the RSI scores for these combinations ranged from 2.0 to 37.6 (Table 2). These differences between the two models are attributable to use of categorisation in the 1995 SI model, use of duration per exertion in place of duty cycle in the RSI model, and to a lesser degree differences between the multipliers used in the two models.

Discussion

The RSI is an exposure assessment methodology based on multiplicative interactions among five task variables. In this regard, it is conceptually similar to the 1995 SI and the recommended weight limit from the Revised NIOSH Lifting Equation (Waters et al. 1993). The multiplicative nature of the interactions among the task variables for risk of DUE MSDs is consistent with epidemiological studies of DUE MSDs (Moore and Garg 1995; Knox and Moore 2001; Moore, Rucker, and Knox 2001; Drinkaus et al. 2003; Bovenzi et al. 2005; Drinkaus et al. 2005; Moore et al. 2006; Silverstein et al. 2006; Spielholz et al. 2008; Harris-Adamson et al. 2011; Garg et al. 2012; Meyers, Gerr, and Fethke 2014; Garg et al. 2014; Kapellusch et al. 2014). While similar to the 1995 SI, the RSI has certain important improvements such as use of continuous rather than categorical multipliers, and duration per exertion rather than duty cycle.

Categorical multipliers pose two problems. First, so long as the task physical demands, as described by the 1995 SI variables, remain in their respective categories, the 1995 SI score does not change. Thus there is no distinction between, for example, 10–29% MVC, or 4–8 efforts per minute, and this can make prioritisation and implementation of task interventions somewhat challenging. To demonstrate this, consider certain combinations of intensity of exertion, efforts per min and duty cycle that produce a 1995 SI score of 6.5, which slightly exceeds the current safe threshold limit of 6.1. The same combinations of these variables result in RSI scores ranging from 1.0 to more than 70 (see Figure 2). Thus, the RSI should prove to be a more useful tool for prioritising task interventions. Second, as measured physical exposure variables (e.g. % MVC, efforts per minute) reach their category limits in the 1995 SI, serious problems may occur with risk classifications. For example, consider a task requiring 29% MVC, 6 efforts per minute of 5s each, fair posture, fair speed and task performance for 8 h per day. The 1995 SI score is 4.5 ('safe'). If %MVC is increased slightly to 30%, and all other task variables are kept the same, the 1995 SI score jumps to 9 ('hazardous'), suggesting that risk has doubled when in fact it has changed very little. Similarly, a task requiring 50% MVC, 4 efforts per minute, duty cycle of 20%, fair posture and speed, and task performance for 8 h per day receives a 1995 SI score of 9 ('hazardous'). If the efforts per minute are reduced to 3, the duty cycle is increased from 20 to 25%, and all other variables remain the same, the 1995 SI score drops in half to 4.5 ('safe'). Thus, the 1995 SI score doubles if we replace 3 efforts per minute of 5s each with 4 efforts per minute of 3s each. These sudden changes in model score and implied risk are inappropriate and have been corrected with the continuous multipliers in the RSI.

The 1995 SI treats frequency of exertion (efforts per minute) and duty cycle as independent variables, but duty cycle is mathematically related to frequency, thus a 'double penalty' occurs, especially for high-frequency exertions. By using duration per exertion, the RSI corrects this problem while still indirectly accounting for duty cycle (which is the mathematical product of frequency and duration per exertion within a period). The use of duration per exertion allows the RSI to explicitly account for tasks with a substantial static component (i.e. localised muscle fatigue). It also allows the RSI to study very low per cent MVC, very high frequency, short duration exertions such as those used for keyboarding tasks. This change makes the RSI a more generally applicable job analysis and design tool than the 1995 SI.

Another important change is the RSI intensity of exertion multiplier. The 1995 SI used a five-point scale for intensity of exertion that was somewhat insensitive to moderate and especially low intensities of exertion (0–29% MVC). An error in force rating by the analyst on the low end of the scale (i.e. an intensity of exertion rating of 2 rather than 1) causes the intensity of exertion multiplier to increase from 1 to 3, which results in a tripling the 1995 SI score and thus the implied risk of DUE MSDs. For applications in the field, we believe that the use of the 10-point Borg CR-10 scale to rate the force, and the use of a continuous intensity of exertion multiplier, will reduce risk misclassifications associated with underestimation or overestimation of the intensity of exertion (force).

Finally, the 1995 SI caps the efforts per minute multiplier at 20 and thus jobs with very high efforts per minute might not receive adequate penalty. In this regard, Garg et al. (2012) noted that 60% of the jobs in their study required more than 20 efforts per minute. The RSI efforts per minute variable and multiplier have no upper limits and thus the RSI can analyse tasks with several dozen or even more than 100 efforts per minute (e.g. wiring, keyboarding). However, the RSI efforts per minute multiplier is designed to ensure that very high-frequency tasks (i.e. efforts per minute more than 90) also have very low force requirements and/or are performed for a very low number of hours per day in order to be classified as 'safe'.

Ideally, the RSI multipliers should be based on epidemiological studies that quantify the relationships between each of the RSI variables and actual risk of DUE MSDs. Unfortunately, this approach is currently infeasible. In the absence of epidemiological studies demonstrating these relationships, one would like to use explicit mathematical relationships between the physical exposure variables and some biomechanical, physiological and/or psychophysical responses. However, even these relationships are substantially lacking. Thus, we have relied heavily on published and many unpublished laboratory studies to inform our professional judgement and design the RSI multipliers. In this regard, we considered various combinations of %MVC, duration per exertion and efforts per min and compared them with published and unpublished data, or performed laboratory simulations to determine whether combinations were feasible or were likely to cause excessive fatigue. While the RSI multipliers were objectively developed, we relied on professional judgement to fill in gaps and resolve discrepancies between available data. Thus, the RSI multipliers are subject to criticism and may need revisions as additional quantitative psychophysical, biomechanical, physiological and/or epidemiological data become available. In particular, as compared to the 1995 SI, we substantially reduced the duration of exposure per day multiplier for extended work shifts beyond 8 h per day. Little is known about the possible increase in MSDs risk based on an increase in exposure from 8 to 12 h. A safe level of physical exposure for an extended work shift (e.g. 12 h) will likely be affected by factors such as the number of days per week of extended exposure, work patterns within the shift and week, recovery time between shifts and other biomechanical and physiological stressors and changes in those stressors. The RSI does not account for these potentially important modifiers of physical exposure. Thus, it should be noted that the hours per day multiplier of 1.2 for an extended work shift of 12 h per day may not be sufficiently protective under certain exposure conditions and may need to be revised as more epidemiological information becomes available. Practitioners should exercise care and judgement when designing extended work shifts beyond 8 h per day.

Similarly, the RSI does not include the 'speed of work' variable. Thus, it may not adequately capture physical exposure from those tasks that require very rapid arm and/or hand/wrist movements.

Conclusion

The RSI is a five-variable model using continuous multipliers. Compared to the 1995 SI, the RSI replaces duty cycle with duration per exertion, and the multipliers reflect more recent research findings. We believe that the RSI is a substantial improvement over the 1995 SI, provides greater discrimination of risk predictions, avoids misclassification of risk due to use of categorical multipliers and should prove useful for both task design and intervention. An RSI score of 10 or less is considered 'safe' and a score greater than 10 is considered 'hazardous'. Similar to the 1995 SI, the RSI is designed to determine risk of DUE MSDs among a cohort of workers who perform the same task. It is not designed to determine the risk of DUE MSDs to an individual worker.

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References

American Conference of Governmental Industrial Hygienists (ACGIH). 2002. *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment*. Cincinnati, OH: ACGIH Worldwide.

Armstrong, T. J., L. J. Fine, S. A. Goldstein, Y. R. Lifshitz, and B. A. Silverstein. 1987. "Ergonomics Considerations in Hand and Wrist Tendinitis." *The Journal of Hand Surgery* 12 (5): 830–37. W.B. Saunders. doi:10.1016/S0363-5023(87)80244-7.

Bernard, B. P. 1997. *Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back*. Cincinnati, OH: NIOSH.

Borg, E., and L. Kaijser. 2006. "A Comparison between Three Rating Scales for Perceived Exertion and Two Different Work Tests." *Scandinavian Journal of Medicine & Science in Sports* 16 (1): 57–69. doi:10.1111/j.1600-0838.2005.00448.x.

Borg, G. A. V. 1982. "Psychophysical Bases of Perceived Exertion." *Medicine and Science in Sports and Exercise* 14 (5): 377–381.

Bovenzi, M., and C. T. J. Hulshof. 1998. "An Updated Review of Epidemiologic Studies on the Relationship Between Exposure to Whole-Body Vibration and Low Back Pain." *Journal of Sound and Vibration* 215 (4): 595–611. doi:10.1006/jsvi.1998.1598.

Bovenzi, M., A. D. Vedova, P. Nataletti, B. Alessandrini, and T. Poian. 2005. "Work-Related Disorders of the Upper Limb in Female Workers Using Orbital Sanders." *International Archives of Occupational and Environmental Health* 78 (4): 303–310. doi:10.1007/s00420-004-0574-6.

Burt, S. E., K. Crombie, Y. Jin, S. Wurzelbacher, J. Ramsey, and J. A. Deddens. 2011. "Workplace and Individual Risk Factors for Carpal Tunnel Syndrome." *Occupational and Environmental Medicine* 68 (12): 928–933. doi:10.1136/oem.2010.063677.

Byström, S. E., and A. Kilbom. 1990. "Physiological Response in the Forearm During and After Isometric Intermittent Handgrip." *European Journal of Applied Physiology and Occupational Physiology* 60 (6): 457–466.

Chiang, H. C., Y. C. Ko, S. S. Chen, H. S. Yu, and T. N. Wu. 1993. "Prevalence of Shoulder and Upper-Limb Disorders Among Workers in the Fish-Processing Industry." *Scandinavian Journal of Work Environment & Health* 19 (2): 126–131. doi:10.2307/40966124.

Cykana, L. 2002. "Grip and Wrist Strength as a Function of Wrist Posture and Hand Tool Center of Mass Offset." *Master's Thesis*, Advisor: Arun Garg. University of Wisconsin – Milwaukee, Milwaukee, WI.

Dahalan, J. B., and J. E. Fernandez. 1993. "Psychophysical Frequency for a Gripping Task." *International Journal of Industrial Ergonomics* 12 (3): 219–230. doi:10.1016/0169-8141(93)90028-C.

Davis, P. J., and J. E. Fernandez. 1994. "Maximum Acceptable Frequencies for Females Performing a Drilling Task in

Different Wrist Postures." *Journal of Human Ergology* 23 (2): 81–92.

Dempsey, P. G., R. W. McGorry, and W. S. Maynard. 2005. "A Survey of Tools and Methods Used by Certified Professional Ergonomists." *Applied Ergonomics* 36 (4): 489–503. doi:10.1016/j.apergo.2005.01.007.

Drinkaus, P., R. Sesek, D. Bloswick, T. Bernard, B. Walton, B. Joseph, G. Reeve, and J. H. Counts. 2003. "Comparison of Ergonomic Risk Assessment Outputs From Rapid Upper Limb Assessment and the Strain Index for Tasks in Automotive Assembly Plants." *Work (Reading, Mass)* 21 (2): 165–172. IOS Press.

Drinkaus, P., R. Sesek, D. S. Bloswick, C. Mann, and T. Bernard. 2005. "Job Level Risk Assessment Using Task Level ACGIH Hand Activity Level TLV Scores: A Pilot Study." *International Journal of Occupational Safety and Ergonomics.* 11 (3): 263–281.

Fan, Z. J., C. Harris-Adamson, F. E. Gerr, E. A. Eisen, K. T. Hegmann, S. S. Bao, B. A. Silverstein, et al. 2015. "Associations Between Workplace Factors and Carpal Tunnel Syndrome: A Multi-Site Cross Sectional Study." *American Journal of Industrial Medicine* 58 (5): 509–518. doi:10.1002/ajim.22443.

Gallagher, S., and J. R. Heberger. 2013. "Examining the Interaction of Force and Repetition on Musculoskeletal Disorder Risk: A Systematic Literature Review." *Human Factors* 55 (1): 108–124. doi:10.1177/0018720812449648.

Garg, A., and J. M. Kapellusch. 2011. "Job Analysis Techniques for Distal Upper Extremity Disorders." *Reviews of Human Factors and Ergonomics* 7 (1): 149–196. doi:10.1177/1557234X11410386.

Garg, A., J. M. Kapellusch, K. T. Hegmann, J. J. Wertsch, A. S. Merryweather, G. Deckow-Schaefer, E. J. Malloy, and WISTAH Hand Study Research Team. 2012. "The Strain Index (SI) and Threshold Limit Value (TLV) for Hand Activity Level (HAL): Risk of Carpal Tunnel Syndrome (CTS) in a Prospective Cohort." *Ergonomics* 55 (4): 396–414. doi:10.1080/00140139.2011.644328.

Garg, A., J. M. Kapellusch, K. T. Hegmann, M. S. Thiese, A. S. Merryweather, Y.-C. Wang, and E. J. Malloy. 2014. "The Strain Index and TLV for HAL: Risk of Lateral Epicondylitis in a Prospective Cohort." *American Journal of Industrial Medicine* 57 (3): 286–302. doi:10.1002/ajim.22279.

Garg, A., L. Cykana, and K. T. Hegmann. 2003. "Effects of Center of Mass and Wrist Posture on Maximum Grip Strength, Wrist Strength and Grip Force." *Proceedings of the 15th International Ergonomics Association Congress,* Seoul: Korea.

Harris-Adamson, C., E. A. Eisen, J. M. Kapellusch, A. Garg, K. T. Hegmann, M. S. Thiese, A. M. Dale, et al. 2015. "Biomechanical Risk Factors for Carpal Tunnel Syndrome: A Pooled Study of 2474 Workers." *Occupational and Environmental Medicine* 72 (1): 33–41. doi:10.1136/oemed-2014-102378.

Harris-Adamson, C., E. Eisen, R. Goldberg, N. Krause, and D. M. Rempel. 2011. "1st Place, PREMUS Best Paper Competition: Workplace and Individual Factors in Wrist Tendinosis among Blue-Collar Workers – the San Francisco Study." *Scandinavian Journal of Work, Environment & Health* 37 (2): 85–98. doi:10.5271/sjweh.3147.

Kapellusch, J. M., A. Garg, K. T. Hegmann, M. S. Thiese, and E. J. Malloy. 2014. "The Strain Index and ACGIH TLV for HAL: Risk of Trigger Digit in the WISTAH Prospective Cohort." *Human Factors* 56 (1): 98–111. doi:10.1177/0018720813493115.

Kim, C.-H., and J. E. Fernandez. 1993. "Psychophysical Frequency for a Drilling Task." *International Journal of Industrial Ergonomics.* 12 (3): 209–218. doi:10.1016/0169-8141(93)90027-B.

Klein, M. G., and J. E. Fernandez. 1997. "The Effects of Posture, Duration, and Force on Pinching Frequency." *International Journal of Industrial Ergonomics* 20 (4): 267–275. doi:10.1016/S0169-8141(96)00059-5.

Knox, K., and J. S. Moore. 2001. "Predictive Validity of the Strain Index in Turkey Processing." *Journal of Occupational and Environmental Medicine* 43 (5): 451–462.

Mani, L., and F. E. Gerr. 2000. "Work-Related Upper Extremity Musculoskeletal Disorders." *Primary Care* 27 (4): 845–864.

Marley, R. J., and J. E. Fernandez. 1995. "Psychophysical Frequency and Sustained Exertion at Varying Wrist Postures for a Drilling Task." *Ergonomics* 38 (2): 303–325. doi:10.1080/00140139508925106.

Melchior, M., Y. Roquelaure, B. Evanoff, J.-F. Chastang, C. Ha, E. Imbernon, M. Goldberg, A. Leclerc, and Pays de la Loire Study Group. 2006. "Why Are Manual Workers at High Risk of Upper Limb Disorders? The Role of Physical Work Factors in a Random Sample of Workers in France (the Pays De La Loire Study)." *Occupational and Environmental Medicine* 63 (11): 754–761. doi:10.1136/oem.2005.025122.

Meyers, A. R., F. E. Gerr, and N. B. Fethke. 2014. "Evaluation of Alternate Category Structures for the Strain Index: An Empirical Analysis." *Human Factors* 56 (1): 131–142.

Mital, A. 1983. "The Psychophysical Approach in Manual Lifting–A Verification Study." *Human Factors* 25 (5): 485–491.

Moore, J. S., and A. Garg. 1994. "Upper Extremity Disorders in a Pork Processing Plant: Relationships between Job Risk Factors and Morbidity." *American Industrial Hygiene Association Journal* 55 (8): 703–715. doi:10.1080/15428119491018592.

Moore, J. S., and A. Garg. 1995. "The Strain Index: A Proposed Method to Analyze Jobs for Risk of Distal Upper Extremity Disorders." *American Industrial Hygiene Association Journal* 56 (5): 443–458. doi:10.1080/15428119591016863.

Moore, J. S., G. A. Vos, J. P. Stephens, E. Stevens, and A. Garg. 2006. "The Validity and Reliability of the Strain Index." *Proceedings of the 16th International Ergonomics Association World Congress*, Netherlands: Maastricht.

Moore, J. S., N. P. Rucker, and K. Knox. 2001. "Validity of Generic Risk Factors and the Strain Index for Predicting Nontraumatic Distal Upper Extremity Morbidity." *American Industrial Hygiene Association Journal* 62 (2): 229–235. doi:10.1080/15298660108984626.

Osorio, A. M., R. G. Ames, J. Jones, J. Castorina, D. M. Rempel, W. Estrin, and D. Thompson. 1994. "Carpal Tunnel Syndrome among Grocery Store Workers." *American Journal of Industrial Medicine* 25 (2): 229–245. doi:10.1002/ajim.4700250209.

Rucker, N., and J. S. Moore. 2002. "Predictive Validity of the Strain Index in Manufacturing Facilities." *Applied Occupational and Environmental Hygiene* 17 (1): 63–73. doi:10.1080/104732202753306177.

Seo, N., T. J. Armstrong, and J. G. Young. 2010. "Effects of Handle Orientation, Gloves, Handle Friction and Elbow Posture on Maximum Horizontal Pull and Push Forces." *Ergonomics* 53 (1): 92–101. doi:10.1080/00140130903389035.

Shih, Y.-C., and Y.-C. Ou. 2005. "Influences of Span and Wrist Posture on Peak Chuck Pinch Strength and Time Needed to Reach Peak Strength." *International Journal of Industrial Ergonomics* 35 (6): 527–536. doi:10.1016/j.ergon.2004.12.002.

Silverstein, B. A., L. J. Fine, and T. J. Armstrong. 1987. "Occupational Factors and Carpal Tunnel Syndrome." *American Journal of Industrial Medicine* 11 (3): 343–358.
Silverstein, B. A., Z. J. Fan, D. K. Bonauto, S. S. Bao, C. K. Smith, N. Howard, and E. Viikari-Juntura. 2010. "The Natural Course of Carpal Tunnel Syndrome in a Working Population." *Scandinavian Journal of Work, Environment & Health* 36 (5): 384–393.
Silverstein, B. A., Z. J. Fan, S. S. Bao, N. Howard, P. Spielholz, C. K. Smith, D. K. Bonauto, and E. Viikari-Juntura. 2006. "How Well Does the Strain Index Predict Carpal Tunnel Syndrome?" *Proceedings of the 16th International Ergonomics Association World Congress*, Netherlands: Masstricht.
Spielholz, P., S. S. Bao, N. Howard, B. A. Silverstein, Z. J. Fan, C. K. Smith, and C. Salazar. 2008. "Reliability and Validity Assessment of the Hand Activity Level Threshold Limit Value and Strain Index Using Expert Ratings of Mono-Task Jobs." *Journal of Occupational and Environmental Hygiene* 5 (4): 250–257. doi:10.1080/15459620801922211.
Stephens, J. P. 2006. *An Analysis of Muscle Fatigue due to Complex Tasks and its Relation to the Strain Index*. Advisor: J. S. Moore. Texas A&M University, College Station, TX.
Waters, T. R., V. Putz-Anderson, A. Garg, and L. J. Fine. 1993. "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks." *Ergonomics* 36 (7): 749–776. doi:10.1080/00140139308967940.

Appendix 1. Tables summarising the Revised Strain Index Multipliers

Table A1. Intensity of exertion (force) ratings and associated multipliers.

% MVC (%)	Borg CR-10	Multiplier
1	–	0.53
5	0.5	1.01
10	1	1.57
15	–	2.10
20	2	2.62
25	–	3.14
30	3	3.71
40	4	5.02
50	5	6.70
60	6	8.79
70	7	11.51
80	8	15.08
90	9	19.70
100	10	25.61

Table A2. Exertions per minute (frequency) ratings and associated multipliers.

Efforts per minute	Multiplier
0.2	0.15
0.5	0.23
1.0	0.35
1.5	0.48
2.0	0.60
3.0	0.85
4.0	1.10
5.0	1.35
7.5	1.98
10.0	2.60
15.0	3.85
20.0	5.10
30.0	7.60
45.0	11.35
60.0	15.10
75.0	18.85
90.0	22.60
120.0	39.71
150.0	61.50

Table A3. Duration per exertion ratings and associated multipliers.

Duration per exertion (s)	Multiplier
0.20	`0.51
0.50	0.61
0.75	0.68
1.00	0.76
1.50	0.92
2.00	1.07
3.00	1.38
5.00	2.00
7.50	2.78
10.00	3.55
20.00	6.65
30.00	9.75
60.00	19.05
90.00	26.82
120.00	32.34
240.00	45.62

Table A4. Hand/wrist posture ratings and associated multipliers.

Hand/wrist posture[a]	Multiplier
75º Flexion	2.16
60º Flexion	1.86
45º Flexion	1.60
30º Flexion	1.37
15º Flexion	1.17
5º Flexion	1.06
Neutral	1.00
5º Extension	1.00
15º Extension	1.00
30º Extension	1.00
45º Extension	1.06
60º Extension	1.25

[a]Measured relative to anatomical neutral.

Table A5. Hours per day ratings and associated multipliers.

Hours per day	Multiplier
0.25	0.36
0.50	0.44
1.00	0.52
1.50	0.58
2.00	0.62
3.00	0.70
4.00	0.77
6.00	0.89
8.00	1.00
10.00	1.10
12.00	1.20