**Final Report**

HOW TO IMPROVE THE REVISED STRAIN
  
INDEX TO ENABLE THE QUANTIFICATION
  
OF FORCES THAT CHANGE DURING
  
PHYSICAL EXERTION

BY:

**Lukas Mitterlehner**University of Applied Sciences Upper Austria
  
School of Medical Engineering and Applied Social Sciences
  
Department of Medical Engineering

Garnisonstraße 21, A-4020 Linz

CARRIED OUT AT:

University of Wisconsin Milwaukee
  
College of Health Sciences
  
2400 E. Hartford Ave.
  
Milwaukee, WI 53211

SUPERVISOR AT HOST UNIVERSITY

**Jay Kapellusch, PhD**Associate Professor, Chair
  
Occupational Science & Technology
  
UWM, College of Health Sciences

SUPERVISOR AT HOME UNIVERSITY

**Dr. Thomas Haslwanter**Professor for Rehabilitation Technology
  
Department of Medical Engineering
  
University of Applied Sciences Upper Austria
  
School of Medical Engineering and Applied Social Sciences

**Declaration**

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

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| Linz, March 4, 2019 |  |  |
| 2 | Lukas Mitterlehner |

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**Abstract**

This report summarizes a three-part study regarding the Revised Strain Index (RSI) that was conducted at the University of Wisconsin-Milwaukee. The RSI is a distal upper extremity physical exposure assessment model that has been published in 2016. The three aims of this study were to (1) test the model assumptions of the existing RSI method, (2) propose an algorithm that addresses limitations of the current model, and (3) provide an applications manual for practitioners on how to apply the RSI.

Results of the pilot study support the current model assumptions. Participants were able to distinguish the difference between tasks from three different RSI score ranges. Further, the perceived exertion corresponds with the actual RSI score.

The proposed algorithm is believed to substantially improve upon the RSI. It enables the quantification of variable force and posture scenarios without sacrificing any of the current model's strengths.

The applications manual provides information about (1) where exertions start and stop, (2) how to count exertions, and (3) how to quantify hand/wrist posture.

**Kurzfassung**

Dieser Bericht stellt die Zusammenfassung einer dreiteiligen Studie zum Thema Re-vised Strain Index (RSI), welche an der University of Wisconsin-Milwaukee durchge-fuehrt wurde, dar. Bei dem RSI handelt es sich um ein Modell zur Bestimmung der physischen Beanspruchung der distalen oberen Extremitaet, welches im Jahr 2016 publiziert wurde. Die drei Ziele der Studie waren (1) das Testen der Annahmen der aktuellen RSI Methode, (2) die Entwicklung eines Algorithmus, welcher die Einschraenkungen des aktuellen Modells adressiert, und (3) das Bereitstellen einer Anleitung zur Verwendung des RSI.

Die Resultate der Pilot-Studie bekraeftigen die derzeitigen Annahmen. Teilnehmer an der Studie waren in der Lage, zwischen Arbeiten aus unterschiedlichen RSI-Wertebereichen zu unterscheiden. Weiters korrelliert die wahrgenommene Anstren­gung mit den tatsaechlichen RSI Werten.

Vom vorgeschlagenen Algorithmus wird geglaubt, dass dieser eine wesentliche Verbesserung gegenueber dem RSI darstellt. Er ermoeglicht die Quantifizierung von Arbeiten mit variablen Kraeften und Handgelenksstellungen, ohne dabei etwaige Staerken des aktuellen Modells einzubuessen.

Die bereitgestellte Anleitung liefert Aufschluss ueber (1) Start- und Stoppzeitpunkt einer Anstrengung (2) das Zaehlen der einzelnen Anstrengungen, und (3) die Quan­tifizierung der Handgelenksstellung.

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**Executive Summary**

The present report summarizes a three-part study regarding the Revised Strain Index (RSI). The study aimed to (1) test the model assumptions of the existing RSI method, (2) propose an algorithm that addresses limitations of the current model, and (3) provide an applications manual for practitioners and ergonomists on how to apply the RSI.

For testing the model assumptions, a pilot study was designed and carried out. Three participants performed 15 unique tasks with various input variable combina-tions. 5 tasks each ranged within scores from (1) 2.98 to 3.37, (2) 9.23 to 12.00, and (3) 30.04 to 34.32. The main objective of the pilot testing was to find out whether or not the perceived exertion correlates with the RSI scores and whether the participants are able to distinguish between tasks of the three different RSI score ranges. The perceived exertion on the Borg CR-10 scale ranged from (1) 2.000 ± 0.906, (2) 4.530 ± 1.390, and (3) 8.730 ± 1.350. A coefficient of determination of 0.903 indicates that the perceived exertion correlates with the RSI score. Further, ANOVA and post-hoc Tukey indicate a statistically significant difference between the means of the three groups.

A novel algorithm is proposed that is believed to enable the quantification of both variable force and posture scenarios. The approach is based on slicing an exertion in a finite number of segments on the time axis. By dividing the exertion in multiple slices on the time axis instead of using averaging or peak force level methods, biomechanical stressors will neither be under- nor overestimated.

The applications manual is built upon the findings of multiple EMG measure-ments. EMG signals of three participants were recorded from five locations on the forearm while performing several tasks. Equipment and software from the company Biometrics Ltd was used for signal acquisition. The results suggest following rules and advises for the application of the RSI: (1) an exertion starts with the initial contact and stops either by loosening the grasp or by a substantial change in mag-nitude or direction of force, and (2) by now, goniometers are the most reliable tool for accurately quantifying hand/wrist posture.

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**Introduction**

Musculoskeletal disorders (MSDs) are soft-tissue injuries that can affect the muscles, nerves, tendons, ligaments, joints, cartilage and spinal discs in the upper and lower limbs, neck and lower back. Possible natures of these injuries or illnesses are a pinched nerve, sprain, strain, tear, pain, hernia, or other similar type of injury in which the causal event is a sudden or sustained exposure to repetitive motion including microtasks, force, vibration, or awkward positions [1][2][3]. Examples of MSDs include carpal tunnel syndrome (CTS), trigger finger, tarsal tunnel syndrome, de Quervain's disease, epicondylitis, tendonitis, Raynaud's phenomenon, rotator cuff syndrome, sciatica, herniated spinal disc, low back pain and carpet layer's knee[3].

According to the Occupational Safety and Health Administration, an injury or ill-ness is considered to be work-related if an event or exposure in the work environment either caused or contributed to the resulting condition or significantly aggravated a pre-existing condition [2].

In 2015, there were 356,910 work-related musculoskeletal disorders (WMSDs) that required at least one day away from work [4]. The incidence rate of MSD injuries decreased to 32.2 days-away-from-work cases per 10,000 workers in 2015 [4], down from 35.8 cases per 10,000 workers in 2013 [5]. Sprains, strains and tears accounted for 36.6% of total workplace injuries and illnesses [4].

According to the 2014 Liberty Mutual Workplace Safety Index, overexertion and repetitive motion injuries rank among the ten most costly injuries to industry, ac-counting for 35.6% of total costs in 2012 [6]. There is a slight decrease to 33.2% in 2015 [7]. This is equal to $21.2 billion and $19.4 billion, respectively, spent by businesses. Repetitive motion injuries alone cost the industry $1.8 billion (3.1%) in 2012 [6] and $1.5 billion (2.6%) in 2015 [7].

In 2018, Howard [8] published an analysis of workers' compensation claims for Washington State from 2006 to 2015. Of these claims, 42.2% of all WMSD claims were for an upper extremity injury. Upper extremity includes shoulder, upper arm, elbow, lower arm, wrist, hand and fingers. Distal upper extremity (DUE) refers to the entire upper extremity, except shoulder [3].

**Ergonomic job analysis methods**

This brief literature review reveals that U.S. businesses spend more than one billion dollars a week on WMSDs, with distal upper extremity disorders being amongst the most cost intensive injuries suffered in industry today. Also, it indicates a declining trend of the overall incidence rate of WMSDs. This decline might be related to the development of ergonomic job analysis methods.

Findings of scientific research have identified physical, psychosocial/organizational and individual occupational risk factors for the development of work-related mus-

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culoskeletal disorders [9]. Occupational risk factors include both overexertion and repetitive motion. Based on those findings, methods for assessing exposure to risk factors for MSDs have been developed. They range from simple checklists to more complex quantitative models [3]. Most of the methods aim to assess the upper re-gions of the body such as the back, neck and upper extremity [9]. Commonly used methods for job analysis to determine the risk of WMSDs are checklists [10], RULA [11], NIOSH Lifting Equation [12] and The Strain Index [13].

**The Revised Strain Index**

The Revised Strain Index (RSI) [14] is a DUE physical exposure assessment model published by Garg, Moore and Kapellusch in 2016. It aims to improve upon the 1995 Strain index by (i) using continuous rather than categorical variables and multipliers, (ii) replacing duty cycle with duration per exertion, and (iii) omitting speed of work.

Thus, the RSI is a five variable model that includes (1) intensity of exertion, (2) efforts per minute, (3) duration per minute, (4) hand/wrist posture, and (5) du-ration per task. The force requirements of a task are represented by the intensity of exertion. It can be estimated using the Borg CR-10 scale [15]. Efforts per minute is synonymous with frequency of exertion. It is a measure of repetitiveness, which is defined as the number of exertions per minute. Duration per exertion stands for the average time that an exertion is applied. Hand/wrist posture refers to the anatomi-cal position of the hand/wrist relative to neutral position. Duration of task per day, which is the last variable of the RSI, is the total time that a task is performed a day.

Currently, due to insufficient data, dose-response relationships between these five variables and the risk of DUE MSDs cannot be specified. Therefore, similar to the 1995 SI, professional judgment was used to derive multiplier values for the RSI. They are consistent with psychophysical, physiological, biomechanical and epidemi-ological considerations and based on the principle that increasing values of intensity of exertion, efforts per minute, duration of exertion, flexion/extension of the wrist and/or duration of task per day increases strain on the body. The RSI score is the product of these five multipliers, as shown below in equation 0.1. A score up to 10.0 is considered 'safe', a score greater than that is considered 'hazardous'. Refer to Garg, Moore and Kapellusch [16] for more details on each multiplier and the corresponding equation.

*RSI = IM* · *EM* · *DM* · *PM* · *HM* (0.1)

IM = Intensity of exertion (force) multiplier

EM = Efforts per minute (frequency) multiplier

DM = Duration per exertion multiplier

PM = Hand/wrist posture multiplier

HM = Duration of task per day multiplier

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**The Composite Strain Index (COSI) and Cumulative Strain Index (CUSI)**

The Revised Strain Index is designed to combine the input variables to evaluate risk of distal upper extremity musculoskeletal disorders for simple, mono-task jobs. However, it is limited to jobs where the constituent variables do not change substan-tially between different exertions within a task cycle and the worker does not rotate between different tasks during a work shift. Often, in contemporary industry, work-ers' jobs consist of more than one task, which again consist of multiple subtasks. A single subtask is defined as unique combination of magnitude of force, duration of force, frequency of exertion and hand/wrist posture.

To meet the requirements of modern industry, the Composite Strain Index (COSI) was designed to quantify exposure when applied hand force and/or duration of that force changes during a task cycle. The Cumulative Strain Index (CUSI) further integrates physical exposure from job rotation [16].

**Limitations of the RSI**

The RSI, in combination with the COSI and CUSI, is believed to be a substantial improvement over the 1995 SI [14][16]. However, there are still certain limitations such as it is not designed to quantify physical exposure of single subtasks with changing input variables.

The main objectives of this research were to (1) test the model assumptions of the existing RSI method, (2) propose an algorithm that addresses the limitations of the current model, and (3) provide an applications manual for practitioners and ergonomists on how to apply the RSI. Each part of this study will be described and discussed in individual chapters of this report. An overall conclusion about every part is followed by a future outlook and suggestions for further research studies.

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**1 Test RSI Assumptions**

As mentioned in chapter , the RSI is believed to be an substantial improvement over the 1995 SI. While both models show good agreement in risk predictions for scores below 3 and above 13.5, the RSI provides much greater discrimination between 'safe' and 'hazardous' within those scores [14]. This was confirmed by comparing the RSI and the 1995 SI based on an application in the dairy sector [17]. However, due to a lack of epidemiological studies, the design of the RSI multipliers relied heavily on laboratory studies and professional judgement [14]. Thus, the first part of this study aimed to test whether or not the perceived exertion correlates with the RSI score in order to either support or reject fundamental model assumptions.

**1.1 Methods**

**Participants**

This pilot study included three healthy participants (two females and one male) ranging in age from 20 to 23. They were all recruited using convenience sampling. Two participants were right-handed, and one was left-handed. None of the them reported a history of musculoskeletal disorders or any other medical condition which would interfere with data collection.

**Study design**

A total of 15 unique input variable combinations was randomly defined. The aim was to design tasks within three different RSI score ranges. 5 tasks each ranged within RSI scores from (1) 2.98 to 3.37, (2) 9.23 to 12.00, and (3) 30.04 to 34.32. Due to the logarithmic relationship between the RSI score and the Borg CR10 scale for perceived exertion, it was assumed that the difference in perception of intensity is approximately the same between range 1 and 2 and range 2 and 3.

For all tasks, a duration of one hour per day and a neutral (0°) hand/wrist posture were assumed. The remaining variables were randomly assigned a value by the author of this report. Refer to table 5.1 in chapter Appendices for the table with an description of all 15 tasks.

**Data collection**

All measurements were carried out using the participants' right hand. First, the maximum voluntary contraction (MVC) was measured using a JAMAR hydraulic hand grip dynamometer with the grip width set to 47.6mm (1.75 inches). The average force was computed out of three trials with two minutes rest between each.

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Chapter 1. Test RSI Assumptions 1.1. Methods

During each trial the participants were sitting in an upright position with the elbow flexed 900. An adjustable arm stand was used to enable a comfortable position for all participants. Measuring the MVC was followed by the actual assumption testing. Therefor an apparatus that has been developed by students at the University of Wisconsin-Milwaukee was utilized. This apparatus connects a weight with a handle that can be compared to a dynamometer. By a pulley, the entire weight force is applied on the handle. The grip width of the handle was set to 51.5mm (2.03 inches). The apparatus can be seen in figure 1.1.

The intensity of exertion was varied by changing weights prior to each task. The participants had to squeeze the handle according to the efforts per minute and dura-tion per exertion for each task. Following every single task, the participants had to rate the perceived exertion based on the Borg CR-10 scale. All tasks were performed for two minutes with at least three minutes rest between each. To avoid possible bias, the tasks were carried out in a random order without sharing the information about the weight with the participants. During each trial the participants were sitting in an upright position with the elbow flexed 90°and a neutral hand/wrist posture.



Figure 1.1: Apparatus for testing RSI assumptions

**Data analysis**

Statistics were computed using RStudio Version 1.1.463.

First, simple linear regression was used to describe the relationship between the RSI scores and the perceived exertion. This was followed by a more detailed ex-amination of the data for the perceived exertion. Grouped by the RSI score range, the residuals of the data were visually checked for normality using QQ-plots. The Shapiro-Wilk test was used to support the findings of the visual inspection. Homo-geneity of variances was checked using Levene's test.

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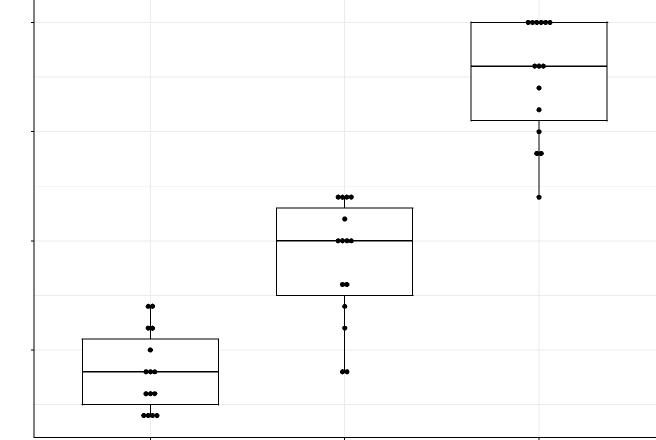
Chapter 1. Test RSI Assumptions 1.2. Results

The one-way analysis of variance (ANOVA) was utilized to determine whether or not there are any statistically significant differences between the means of the groups. The differences between the groups were further investigated using the Post-hoc Tukey procedure. For all tests a 95% confidence interval was specified.

**1.2 Results**

The coefficient of determination of the simple linear regression is 0.903. Figure 1.2 shows the boxplots of the data for the perceived exertion grouped by RSI score range. The corresponding table 1.1 summarizes statistical key figures for each group. The perceived exertion ranged from (1) 2.000 ± 0.906, (2) 4.530 ± 1.390, and (3) 8.730 ± 1.350. Refer to figure 5.1 to figure 5.3 in chapter Appendices for the QQ-plots. P-values for the Shapiro-Wilk tests are 0.056, 0.045 and 0.023 for the ranges 1, 2 and 3, respectively. Leven's test resulted in a p-value of 0.419. Table 1.2 summarizes the ANOVA and table 1.3 the post-hoc Tukey test.

Range1 Range2 Range3



Perceived exertion (Borg−CR10)

10.0

7.5

5.0

2.5

RSI score

Figure 1.2: Perceived exertion grouped by RSI score range

Table 1.1: Summary of the descriptive statistics for the perceived exertion grouped by RSI score range

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Group | n | Mean | SD | Median | Variance |
| Range 1 | 15 | 2.000 | 0.906 | 2.000 | 0.821 |
| Range 2 | 15 | 4.530 | 1.390 | 5.000 | 1.950 |
| Range 3 | 15 | 8.730 | 1.350 | 9.000 | 1.820 |

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Chapter 1. Test RSI Assumptions 1.3. Discussion

Table 1.2: Summary of the one-way ANOVA

df SS MS F p-value

Ranges 2 346.978 173.489 113.556 <2e-16

Error 42 64.167 1.528

Total 44 411.145

Table 1.3: Summary of the post-hoc Tukey test

Diff Lwr Upr p-value

Range 2 - Range 1 2.533 1.437 3.630 4.2e-6

Range 3 - Range 1 6.733 5.637 7.830 0.000

Range 3 - Range 2 4.200 3.103 5.300 0.000

Diff = Difference in the observed means, Lwr = Lower interval, Upr = Upper interval

**1.3 Discussion**

Due to the r-square value of 0.903 it can be assumed that the perceived exertion generally correlates with the RSI score. Also, there is a statistically significant dif-ference between groups as determined by the one-way ANOVA. Further, the Tukey test shows that there is a statistically significant difference between all three groups. The difference between range 1 and range 2 is approximately the same as between range 2 and range 3. This proves the logarithmic relationship between the RSI score and the Borg CR10 scale

ANOVA assumes that the data of each group are normally distributed and that these normal populations have a common variance. The results of all performed tests meet those assumptions and thus ANOVA is valid.

Due to the fact that the apparatus was fixed on a table it was only operable using the right hand. Since this study was not focused on the absolute maximum grip force this is not an issue. Also, the dynamometer grip width that was used for measuring the MVC differed from the apparatus' handle diameter. According to previous studies [18][19][20], the difference lies within a range than can be neglected. It is noteworthy that participants struggled to perform task 13 and task 15. This might be related with the fact that the dynamometer was used to obtain isometric MVC. However, performing the tasks with the apparatus relied on isotonic muscle contraction.

Participants reported that it is almost impossible to maintain a specific posture during an exertion. Thus, this pilot study did not regard the posture and for all tasks it was set 0. In order to regard the posture in future studies, a new apparatus or experiment design seems to be inevitable. Fixing the wrist in place during an exertion might be an appropriate solution.

While the outcome of this pilot study looks promising, the results need to be interpreted with care. The input variables for each task were assigned a value by

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Chapter 1. Test RSI Assumptions 1.3. Discussion

the author but no methods to exclude or control confounding variables were applied. Statistical analysis revealed a statistical difference of the input variables between groups. Also, high RSI scores and high perceived exertions seem to mainly correlate with high intensities of exertion. To exclude confounding variables some tasks were redesigned, and the participants were asked to perform all tasks again. Because the findings of the repeated measurements mainly confirm the first ones, the results of the initial experiment are still assumed to be valid. The results of the redesigned measurements are not presented in this report but are available upon request from the author.

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**2 The Variable Revised Strain Index (VRSI)**

As mentioned in the chapter , the RSI is limited to jobs where the constituent variables do not change substantially between different exertions within a task cycle and the worker does not rotate between different tasks during a work shift. While COSI and CUSI provide a remedy for jobs with changing variables during a full task cycle and regard possible job rotation, they are still not capable to quantify jobs where the input variables change during a single subtask.

For example, when driving a screw into wood or any other material the force requirements vary between every turn of the screwdriver. Currently, different ways of averaging were utilized to analyze jobs like this. However, these methods tend to systematically underestimate the biomechanical stressors. Other approaches use peak force levels, but they are believed to overestimate biomechanical stressors [16].

To address the current limitations, this part of the study aimed to develop an improvement to the RSI that enables the quantification of variable force tasks and neither underestimates nor overestimates biomechanical stressors.

**2.1 Segmentation approach**

To ensure that biomechanical stressors are neither under- nor overestimated, av-eraging or peak force level methods must be avoided. Instead, all changes of the variables during a single exertion must be captured and processed individually. This can be achieved by dividing an exertion into multiple slices on the time axis. For each slice the RSI score can be computed individually. The sum of scores represents the overall RSI score for the entire variable task.

For tasks where the constituent variables do not change there must not be any difference between the segmentation approach and the current RSI. Whether or not this criterion is met is being tested below 2.1. The multipliers for efforts per minute, posture and hours per day were assumed to be 1. The intensity of exertion was assumed to be 40%MVC. This is equivalent to an intensity of exertion multiplier of 5.02.

Both approaches result in a duration multiplier of 1.38. Hence, *RSI* = *IM*·*DM* = 5*.*02 · 1*.*38 = 6*.*93 for both methods.

The example shown in figure 2.1 either assumed all variables to be constant or ignored them completely. However, the proposed segmentation approach is believed to be valid for changing input variables, too.

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Chapter 2. The Variable Revised Strain Index 2.2. (VRSI) VRSI variables and multipliers

(a) Current RSI (b) Segmentation approach

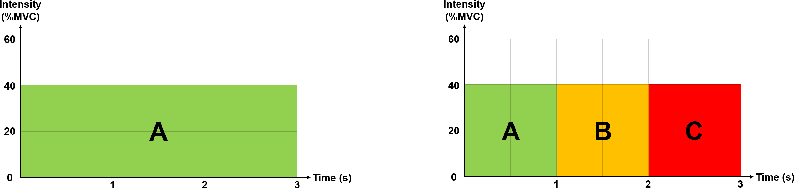


Figure 2.1: Comparison between current RSI and segmentation approach for static input variables

|  |  |
| --- | --- |
| *DM* = *DMA*  = 0*.*45 + 0*.*31(3)  = 1*.*38 | *DM* = *DMA* + (*DMAB* − *DMA*)  + (*DMABC* − *DMAB*)  = 0*.*45 + 0*.*31(1) + [0*.*45 + 0*.*31(2)  − 0*.*45 + 0*.*31(1)] + [0*.*45 + 0*.*31(3)  − 0*.*45 + 0*.*31(2)] |

|  |  |  |  |
| --- | --- | --- | --- |
| = | 0*.*76 | + [1*.*07 − 0*.*76] | + [1*.*38 − 1*.*07] |
| = | 0*.*76 | + 0*.*31 + 0*.*31 |  |
| = | 1*.*38 |  |  |

**2.2 VRSI variables and multipliers**

Basically, the VRSI relies on the same input variables and multipliers as the current RSI. However, some slight adaptions were necessary and the combination of the multipliers for intensity of exertion, duration of exertion, and posture is expressed by the newly introduced Repetition Independent RSI (RIRSI)

|  |  |
| --- | --- |
| *n* | −1 |

*RIRSI* = *DM*1 · *IM*1 · *PM*1 + *X* L*DM* · *IMi*+1 · *PMi*+1 (2.1) *i*=1

where

/*DM* = *DMPi+1*

*j=1 .* − *DM>ij=1 .* (2.2)

RIRSI = Repetition Independent Revised Strain Index

L*DM* = Difference between two adjacent duration of exertion multipliers

*DM*1*, IM*1*, PM*1 = Duration,intensity and posture multiplier for the first slice

*IMi*+1*, PMi*+1 = Intensity and posture multiplier for the upcoming slices

n = Number of finite slices/segments

i = Discrete time block, number of current slice

j = Discrete time block counter, slice counter

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Chapter 2. The Variable Revised Strain Index (VRSI) 2.3. VRSI score

**2.3 VRSI score**

Like the variables and multipliers, the equation for the VRSI score (2.3) is related to the current RSI equation. A score up to 10.0 is considered 'safe', a score greater than that is considered 'hazardous'.

*V RSI* = *RIRSI* · *EM* · *HM* (2.3)

**2.4 VRSI examples**

This section provides three examples of the application of the Variable Revised Strain Index. The first two examples assume constant posture. Efforts per minute multiplier and hours per day multiplier were assumed 1 for all applications. For comparison, each example is followed by computing the current RSI using peak and mean values for force and posture.

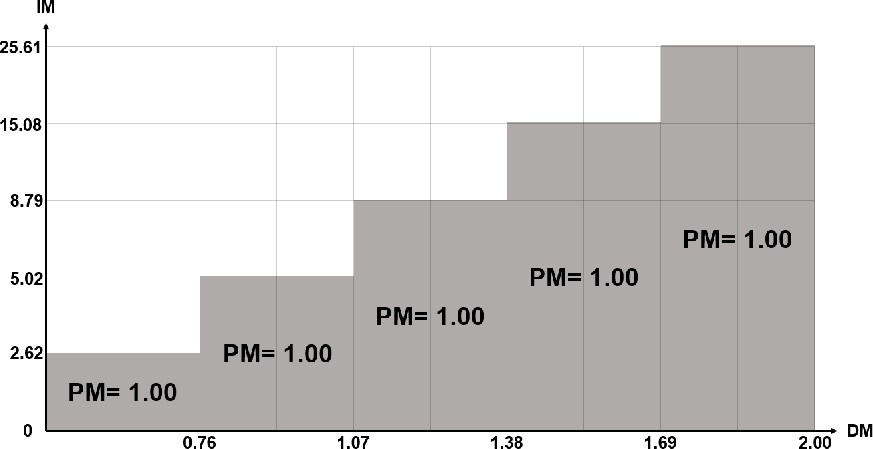


Figure 2.2: VRSI - Example 1

*V RSI* = *RIRSI* · *EM* · *HM* = [*DM1* · *IM1* · *PM1* +

−*1*

X

/*DM* · *IMi+1* · *PMi+1*] · *EM* · *HM*

*n*

*i=1*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| = | 0*.*76 · 2*.*62 · 1*.*00 + [(1*.*07 − 0*.*76) · 5*.*02 | * 1*.*00 |  |  |
|  | + (1*.*38 − 1*.*07) · 8*.*79 · 1*.*00 + (1*.*69 − | 1*.*38) · | 15*.*08 · | 1*.*00 |
|  | + (2*.*00 − 1*.*69) · 25*.*61 | * 1*.*00] | * 1*.*00 · | 1*.*00 |
| = | 1*.*99 + [1*.*56 + 2*.*72 + 4*.*67 + 7*.*94] |  |  |  |
| = | 18*.*88 |  |  |  |

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Chapter 2. The Variable Revised Strain Index (VRSI) 2.4. VRSI examples

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 25*.*61 · 2*.*00 · 1 · 1 · 1

= 51*.*22

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 11*.*43 · 2*.*00 · 1 · 1 · 1

= 22*.*85

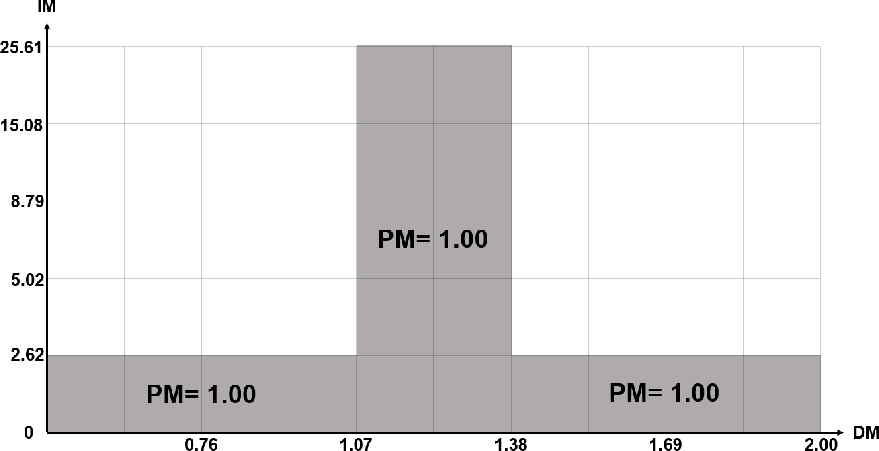


Figure 2.3: VRSI - Example 2

*V RSI* = *RIRSI* · *EM* · *HM* = [*DM1* · *IM1* · *PM1* +

−*1*

X

/*DM* · *IMi+1* · *PMi+1*] · *EM* · *HM*

*n*

*i=1*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| = | 0*.*76 · 2*.*62 | * 1*.*00 | + [(1*.*07 | − 0*.*76) · 2*.*62 · | 1*.*00 |  |  |
|  | + (1*.*38 − | 1*.*07) | * 25*.*61 · | 1*.*00 + (1*.*69 − | 1*.*38) · | 2*.*62 · | 1*.*00 |
|  |  |  | + (2*.*00 | − 1*.*69) · 2*.*62 · | 1*.*00] · | 1*.*00 · | 1*.*00 |

= 1*.*99 + [0*.*81 + 7*.*94 + 0*.*81 + 0*.*81]
  
= 12*.*36

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 25*.*61 · 2*.*00 · 1 · 1 · 1

= 51*.*22

18

Chapter 2. The Variable Revised Strain Index (VRSI) 2.4. VRSI examples

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 7*.*22 · 2*.*00 · 1 · 1 · 1

= 14*.*44

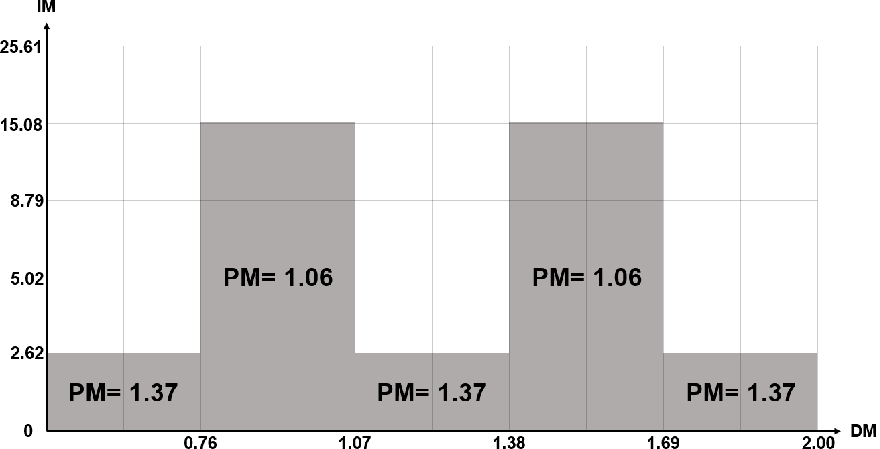


Figure 2.4: VRSI - Example 3

*V RSI* = *RIRSI* · *EM* · *HM* = [*DM1* · *IM1* · *PM1* +

−*1*

X

/*DM* · *IMi+1* · *PMi+1*] · *EM* · *HM*

*n*

*i=1*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| = | 0*.*76 · 2*.*62 · 1*.*37 + [(1*.*07 − 0*.*76) · 15*.*08 · 1*.*06 | |  |  |
|  | + (1*.*38 − 1*.*07) · 2*.*62 · 1*.*37 + (1*.*69 − | 1*.*38) · | 15*.*08 · | 1*.*06 |
|  | + (2*.*00 − 1*.*69) · 2*.*62 | * 1*.*37] | * 1*.*00 · | 1*.*00 |
| = | 2*.*73 + [4*.*96 + 1*.*11 + 4*.*96 + 1*.*11] |  |  |  |
| = | 14*.*87 |  |  |  |

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 15*.*08 · 2*.*00 · 1*.*37 · 1 · 1

= 41*.*87

*RSI* = *IM* · *DM* · *PM* · *EM* · *HM*

= 7*.*22 · 2*.*00 · 1*.*25 · 1 · 1

= 18*.*95

19

Chapter 2. The Variable Revised Strain Index (VRSI) 2.5. Discussion

**2.5 Discussion**

The proposed VRSI is conceptually similar to the RSI since they both are based on the same input variables. Even though either of the methods can be utilized for tasks without changing input variables, the VRSI is intended to be used for the quantification of variable force scenarios. For all three examples this approach returned plausible results. All tasks were considered 'hazardous' by the VRSI, av-eraging and peak force approach. However, the VRSI assigns the lowest score for each example. Initially, it was planned to apply the algorithm on multiple EMG datasets. Unfortunately, due to a lack of time this was not realized. Currently, the VRSI divides the exertion in a finite number of slices. Increasing the number of slices results in higher accuracy. Thus, the final form of the method should be based on an integrating function.

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**3 Applications Manual**

The RSI variables are based on observation and subjective judgement by the practi-tioner or ergonomist. In a recent study about the comparison of the Strain Index and the Revised Strain Index [17], researches are seeking for a more accurate description on how to quantify hand/wrist posture. They concluded that it is especially difficult to evaluate the hand/wrist posture just by observation.

Also, the RSI is a sensitive model and slight changes of the input variables have a perceptible impact on the resulting score. Thus, it is important to provide an applications manual that includes precise instructions and helpful advises on how to obtain the variables.

For that reason, the objective of the last part of this study was to provide guidance on how to obtain the RSI variables. It aims to reduce the variation of RSI scores for the same task between different practitioners. Further, it provides information about (1) where exertions start and stop (duration), (2) how to count exertions, and (3) how to quantify hand/wrist posture.

**3.1 Methods**

**Participants**

The measurements were carried out with the exact same participants as for testing the RSI assumptions in chapter 1. Refer to section 1.1 for a detailed description about the participants.

**Study design**

To investigate (1) where exertions start and stop, (2) how to count exertions, and (3) how to quantify posture, a set of three different tasks was designed. Each experiment was optimized for one of the problems mentioned.

The first task was intended for the determination of the exact start and stop of an exertion. It included simple lifting and horizontally moving of a 5kg weight from one point to another. For the second task, participants had to place a 5kg weight on a wheeled board, horizontally shift the board and then remove the weight from the board. The participants were asked to maintain the grasp during the entire task cycle. The first two tasks were believed to allow conclusions about start and stop of an exertion and how to count them. The last task was designed for analyzing the quantification of hand/wrist posture. The participants had to vary the posture both with and without squeezing a dynamometer.

For all tasks, surface EMG levels were recorded. In addition, each trial was videotaped to enable a synchronization of the signals.

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Chapter 3. Applications Manual 3.1. Methods

**Data collection**

Surface EMG levels for each participant were recorded on the forearm of the dom­inant hand. Biometrics DataLink DLK900, Base Unit and PC Software Version 8.51 were used for data collection. The sampling rate was 1000Hz. Five bipolar electrodes (Biometrics SX230 1000 Surface EMG Sensor) with a fixed electrode dis-tance of 20mm were placed on the (i) m. abducter pollicis longus, (ii) m. flexor digitorum, (iii) m. flexor carpi ulnaris, (iv) m. extensor carpi ulnaris, and (v) m. extensor digitorum. The positioning of the electrodes was verified using test ma-neuvers according to Perotto [21]. Participants' arm and all sEMG electrodes were cleaned using alcohol wipes prior to sensor application. To normalize sEMG sig-nals, participants performed several calibration measurements [22]. A maximum grip exertion was followed by a series of four resisted hand maneuvers: (1) push-ing upwards from neutral, (2) downwards from neutral, (3) outwards from neutral, and (4) inwards from neutral Each maneuver lasted approximately three seconds. Participants then performed the tasks presented beforehand. During each trial the participants were sitting in an upright position. Before each task video recording was started.

For the first task, participants had to grasp a disc-shaped 5kg weight with both hands. This weight had to be lifted and horizontally moved from one point to another. The distance between start- and endpoint was approximately 50cm. After putting down the weight, the grasp was loosened. This cycle was repeated multiple times.

The seconds task was similar to the first one. Again, the 5kg had to be grasped with both hands. It was lifted and placed on a wheeled board. Without loosening the grasp, the board was moved horizontally for approximately 20cm and then the weight was placed back on the table. Now, after putting down the weight, the grasp was loosened. This cycle was repeated several times.

For the third task, participants were sitting in an upright position with the elbow flexed 90°and a neutral hand/wrist posture. An adjustable arm stand was provided to enable a comfortable position. In addition to the sEMG electrodes, a goniometer was mounted on the wrist. Also, the participants were loosely grasping a Biometrics G200 Hand Grip Dynamometer during the entire trial. First, the participants were asked to perform maximum extension for three seconds, followed by neutral position for three seconds and then maximum flexion for three seconds. This was repeated twice, with a one-minute rest between each trial. Capturing maximum posture was followed by increasing posture gradually. Therefor, participants rested the arm in neutral position for three seconds. Then, they increased the wrist posture in 10°steps every three seconds up to 80°flexion, followed by returning to neutral position for three seconds. Lastly, the wrist posture was increased in 10°steps every three seconds up to 60°extension.

The entire third task was repeated, squeezing the dynamometer with 75%MVC.

**Data analysis**

Data processing and analysis was performed with Matlab R2018b Update 2 (9.5.0. 1033004).

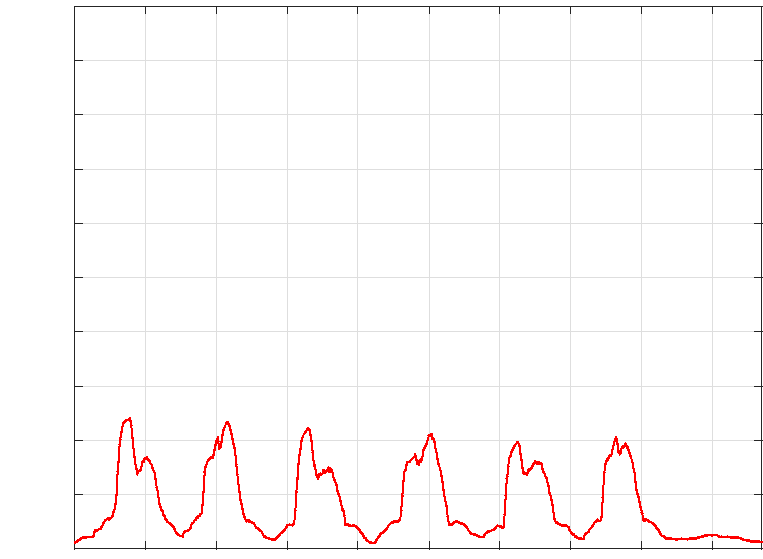
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Chapter 3. Applications Manual 3.2. Results

The raw sEMG signals from all five sensors were bandpass-filtered with specified passband frequencies of 20Hz and 50Hz and a filter order of 4. The filtered signals were transformed using a moving-RMS filter with a 1000 sample window. Then, the RMS filtered sEMG signals were normalized by dividing each signal by its respective maximum amplitude recorded from maximum grip and/or provocative maneuvers [22][23].

**3.2 Results**

Figure 3.1 shows the sEMG signal for task 1. The amplitudes from all electrodes have been combined to one signal. Figure 3.2 presents the sEMG signal for task 2. As for the first task, the amplitudes from all electrodes have been combined to one signal. Figure 3.3 and figure 3.4 provide information about changing the posture both with and without squeezing the dynamometer. The sEMG signals for gradually changing the posture are shown in 3.5 and figure 3.6, respectively.



%MVC

100

40

90

80

70

60

50

30

20

10

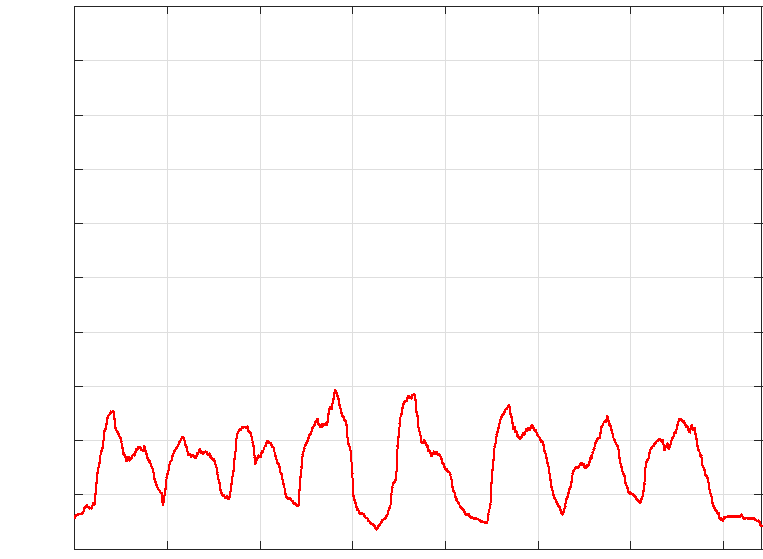
0

|  |  |
| --- | --- |
|  | 5 10 15 20 25 30 35 40 45  Time (s) |

Figure 3.1: Task 1 - Moving a weight: combined sEMG signals of all five electrodes

23

Chapter 3. Applications Manual 3.2. Results



%MVC

100

40

90

80

60

50

30

20

70

10

0

5 10 15 20 25 30 35

Time (s)

Figure 3.2: Task 2 - Moving weight on a board: combined sEMG signals of all five electrodes

Figure 3.3: Task 3 - Maximum posture, hold dynamometer loose: sEMG signals of all five electrodes



60

%MVC

40

20

0

* 10 20 30 40 50 60

Time (s)

60

%MVC

40

20

0

* 10 20 30 40 50 60

Time (s)

0

* 10 20 30 40 50 60

Time (s)

0

* 10 20 30 40 50 60

Time (s)

0

* 10 20 30 40 50 60

Time (s)

60

%MVC

40

20

60

%MVC

40

20

60

%MVC

40

20

M. flexor digitorum



M. abducter pollicis longus



M. flexor carpi ulnaris



M. extensor carpi ulnarix



M. extensor digitorum

24

Chapter 3. Applications Manual 3.2. Results

Figure 3.4: Task 3 - Maximum posture, squeeze dynamometer with 75%MVC: sEMG signals of all five electrodes

0

* 5 10 15 20 25 30 35 40 45

Time (s)

200

%MVC

100

0

* 5 10 15 20 25 30 35 40 45

Time (s)

200

%MVC

100

0

* 5 10 15 20 25 30 35 40 45

Time (s)

200

%MVC

100

0

* 5 10 15 20 25 30 35 40 45

Time (s)

200



M. extensor digitorum

100

0

* 5 10 15 20 25 30 35 40 45

Time (s)

%MVC

200

%MVC

100



M. abducter pollicis longus



M. flexor digitorum



M. flexor carpi ulnaris



M. extensor carpi ulnarix

Figure 3.5: Task 3 - Increase posture gradually, hold dynamometer loose: sEMG signals of all five electrodes



0

* 10 20 30 40 50 60 70

Time (s)

0

* 10 20 30 40 50 60 70

Time (s)

60

0

* 10 20 30 40 50 60 70

Time (s)

0

* 10 20 30 40 50 60 70

Time (s)

0

* 10 20 30 40 50 60 70

Time (s)

60

%MVC

40

20

60

%MVC

40

20

%MVC

40

20

M. extensor carpi ulnarix

60

%MVC

40

20

60

%MVC

40

20



M. abducter pollicis longus



M. flexor digitorum



M. flexor carpi ulnaris



M. extensor digitorum

25

Chapter 3. Applications Manual 3.3. Discussion

Figure 3.6: Task 3 - Maximum posture, squeeze dynamometer with 75%MVC: sEMG signals of all five electrodes

150



M. abducter pollicis longus

%MVC

100

50

0

* 10 20 30 40 50 60 70 80

Time (s)

0

* 10 20 30 40 50 60 70 80

Time (s)

0

* 10 20 30 40 50 60 70 80

Time (s)

0

* 10 20 30 40 50 60 70 80

Time (s)

0

* 10 20 30 40 50 60 70 80

Time (s)

150

%MVC

100

50

150

%MVC

100

50

150

%MVC

100

50

150

%MVC

100

50



M. flexor digitorum



M. flexor carpi ulnaris



M. extensor carpi ulnarix



M. extensor digitorum

**3.3 Discussion**

Due to the fact that the EMG signal and the videotape were not synchronized automatically, this had to be done manually. Unfortunately, both figure 3.1 and figure 3.2 are not as significant as expected. However, they are still acceptable and basic conclusions can be drawn from the results.

There is a noteworthy observation from the figures presenting the changing pos-ture. When holding the dynamometer loose, changes of the posture can be detected with sEMG. This is indicated by an increase of the amplitude from the correspond-ing muscles. Unfortunately, when squeezing the dynamometer with 75%MVC this is no longer possible.

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**4 Conclusion**

Based on the results from the pilot study it can be concluded that the perceived exertion correlates with the RSI score. Furthermore, participants were able to distin-guish the difference between tasks from three different RSI score ranges. However, the results do not allow any conclusion about the limits of the distinction. This means that is unclear within what range the participants were not able to distin-guish two tasks from each other anymore. This issue could be further investigated in future studies. Also, further research should be conducted in order to support the findings of this study with more significant data. Currently, only three par-ticipants performed 15 different tasks. More participants and more input variable combinations should be evaluated.

The proposed VRSI is believed to be an essential improvement over the current RSI. Currently, the method was only applied on fictional tasks. While it has been compared to the averaging and peak force level approach, it has not been proven in any way, yet. For each of the fictional tasks the VRSI assigned the lowest scores, compared to the averaging and peak force level method. By dividing any exertion in multiple slices on the time axis, biomechanical stressors will neither be under- nor overestimated. Next, the assumptions should be tested in an experiment similar to the pilot study presented in this paper.

Multiple conclusion can be drawn for the applications manual. They are mostly also valid for the newly proposed VRSI. The start of an exertion can be defined as the moment of the initial contact with the tool. The end is characterized either by loosening the grasp or by a substantial change in magnitude or direction of force. Especially the second task supports these assumptions. While the weight lies completely on the board, muscle activity can still be noticed with sEMG. This amplitude is believed to be related only with maintaining the grasp. Thus, the end of an exertion is not marked by simply putting down the object.

Based on the findings about the duration of an exertion, assumptions about how to count them can be made. An exertion starts with the initial contact and stops either by loosening the grasp or by a substantial change in magnitude or direction of force. The entire process between start and stop contributes to the duration the exertion.

Regarding posture, it can be concluded that sEMG is not appropriate for observ-ing changes. While it works for tasks with low exertions it fails to detect variations in the posture for tasks with high levels of exertions. By now, goniometers seem to be the only functioning tool for accurately quantifying hand/wrist posture. They provide valid results for every intensity of exertion.

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**5 Future work**

In the course of the discussions of the results at the end of each part of the study it was already mentioned that further studies need to be carried out.

First, the results of the pilot study about the correlation between perceived exer-tion and RSI scores need to be confirmed by a more extensive study. Especially, a larger number of participants needs to be recruited. In addition, more input variable combinations must be investigated. The aim should be to also create tasks with a high RSI score while keeping the intensity of exertion low. Generally, confounding variables must be avoided and no statistically significant differences between the means of the input groups must be present. This can be verified by analyzing the study design using ANOVA.

When testing the RSI assumptions, participants were struggling to perform two tasks. It was already mentioned that this might be related with the fact that the isometric MVC was measured with the dynamometer but for the experiments the weight was moved by isotonic muscle contraction. Future studies are necessary to investigate the relation between isometric and isotonic muscle contraction. The current study ignores hand/wrist posture entirely. Changes of the posture should also be addressed in future studies.

The proposed VRSI has been compared to mean and peak force approaches but the results have not been verified, yet. A similar study like the one for testing the RSI assumptions should be conducted. However, the method itself still needs some improvement. In the future, the VRSI should be based on an integrating function instead of a finite number of slices. An alternative approach would be the use of a linear regression model to explain the

The applications manual is based on multiple EMG measurements. However, some of the signals might not be entirely reliable. Future work should focus on how to count exertions, especially when baseline forces are present. An example for baseline forces is holding a screwdriver or any other tool. Muscle activities can be clearly detected by sEMG. However, it is still not certain whether or not these activities contribute to the development musculoskeletal disorders or whether they can be neglected. For future measurements it is recommended to utilize an equipment that enables synchronization between EMG signals and the video. This would facilitate signal evaluation and provide more accurate results. With improved data analysis it might be possible to extract information about the hand/wrist posture from the EMG signals. However, the use of goniometers is believed to be more efficient.

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**Abbreviations**

**ANOVA** Analysis of variance.

**COSI** Composite Strain Index.
  
**CUSI** Cumulative Strain Index.

**DM** Duration per exertion multiplier.
  
**DUE** Distal upper extremiz.

**EM** Exertions per minute (frequency) multiplier. **EMG** Electromyography.

**HM** Duration of task per day multiplier.
  
**IM** Intensity of exertion (force) multiplier.

**MSDs** Musculoskeletal disorders.
  
**MVC** Maximum voluntary contraction.

**NIOSH** National Institute for Occupational Safety and Health.

**PM** Hand/wrist posture multiplier.

**QQ-Plot** Quantile-Quantile-Plot.

**RIRSI** Repetition Independent Revised Strain Index.

**RMS** Root mean square.

**RSI** Revised Strain Index.

**RULA** Rapid Upper Limb Assessment.

**sEMG** Surface-Electromyography.
  
**SI** Strain Index.

**U.S.** United States.

**VRSI** Variable Revised Strain Index.

**WMSDs** work-related musculoskeletal disorders.

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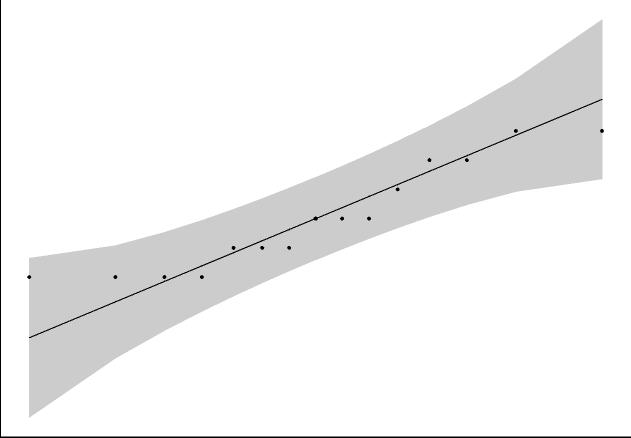
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|  |  |
| --- | --- |
| Sample Quantiles | 2  0  −2 |

Table 5.1: List of all tasks

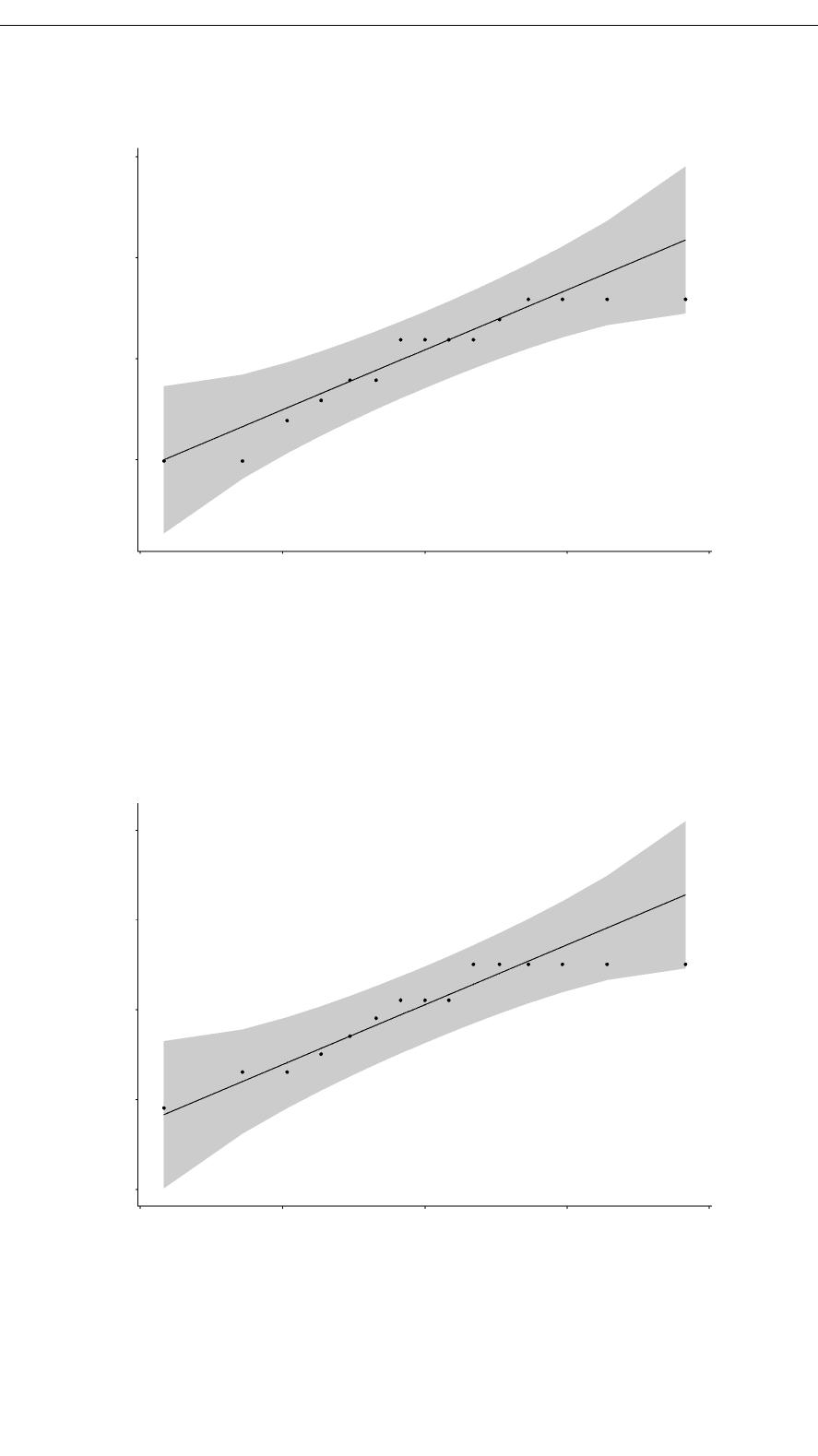
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| # | I (%MVC) | E (Efforts/min) | D (s) | P (°) | H (h) | RSI |
| 1 | 30 | 1 | 10 | 0 | 1 | 2.39 |
| 2 | 20 | 4 | 5 | 0 | 1 | 2.99 |
| 3 | 10 | 1 | 30 | 0 | 1 | 2.79 |
| 4 | 40 | 2 | 5 | 0 | 1 | 3.13 |
| 5 | 90 | 1 | 1 | 0 | 1 | 2.72 |
| 6 | 40 | 10 | 3 | 0 | 1 | 9.36 |
| 7 | 50 | 1 | 25 | 0 | 1 | 9.98 |
| 8 | 80 | 3 | 3 | 0 | 1 | 9.81 |
| 9 | 30 | 5 | 10 | 0 | 1 | 9.22 |
| 10 | 60 | 2 | 10 | 0 | 1 | 9.72 |
| 11 | 70 | 10 | 5 | 0 | 1 | 31.06 |
| 12 | 100 | 1 | 20 | 0 | 1 | 30.91 |
| 13 | 60 | 0.1 | 555 | 0 | 1 | 35.18 |
| 14 | 80 | 2 | 25 | 0 | 1 | 38.50 |
| 15 | 80 | 3 | 15 | 0 | 1 | 33.92 |

−2 −1 0 1 2

Theoretical Quantiles

Figure 5.1: QQ-Plot RSI score range 1

35



5.0

2.5

Sample Quantiles

0.0

−2.5

5.0

2.5

Sample Quantiles

0.0

−2.5

−5.0

List of Tables List of Tables

−2 −1 0 1 2

Theoretical Quantiles

Figure 5.2: QQ-Plot RSI score range 2

−2 −1 0 1 2

Theoretical Quantiles

Figure 5.3: QQ-Plot RSI score range 3

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