Working time and upper limb musculoskeletal symptoms: a longitudinal study among assembly line workers

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Abstract: This study followed assembly line workers during 7 months, comprising a 4-wk season holidays. The main purposes were to determine the potential effect of working time on the presence and intensity of upper limb musculoskeletal symptoms, as to verify the effect of 4 wk of job interruption in the upper limb musculoskeletal symptoms presence and intensity. Data was collected during 6 moments. Generalized estimating equations analyses were used. For the effect estimates, odds ratio with corresponding 95% confidence intervals were reported for each outcome/model. The upper limb musculoskeletal symptoms showed a significant increase (p=0.001), especially after the 4 wk off. In all data collection points there was a significant positive association between the upper limb musculoskeletal symptoms and general health status (p<0.001). Considering symptoms’ intensity, significant relations were found (p<0.001). Work time had a negative effect on the work-related upper limb musculoskeletal symptoms over 7 months (OR 0.909, 95% CI 0.861–0.960, p=0.001). For the intensity of upper limb symptoms, the effect of time was also statistical significant (OR 0.115, 95% CI 0.131–1.220, p=0.008). A 4-wk job interruption did not show an immediately positive effect on upper limb musculoskeletal symptoms presence.

Key words: Work-related upper limb musculoskeletal disorders (WRULMSD), Musculoskeletal symptoms, High-demanding jobs, Automotive assembly, Occupational health

Introduction

Automotive assembly line work is characterized by standardized tasks, frequently addressed as high demanding jobs¹). The highly repetitive work (the same movement two to four times a minute or in cycles below thirty seconds²) with short recovery periods are often related to neck, shoulder, elbow and forearm musculoskeletal disorders³, ⁴). Repetition and force exertion are common in these settings and when both occur over a significant period of time, may lead to cumulative biomechanical loading, causing reduced functional capacity to continue performing the task and maintaining force⁵, ⁶).

That biomechanical exposure, for itself, is an important factor for the development of musculoskeletal
disorders\(^7,8\). This exposure to physically demanding work with insufficient recovery periods may result in the development of the work-related upper limbs musculoskeletal disorders (WRULMSD), one of the most common health problems in automotive assembly lines\(^9\)–\(^14\).

A study on newly employed manufacturing workers found that most of the musculoskeletal disorders (including upper limb disorders) developed in the first twelve months\(^15\). Other studies, in the early 90’s, compared a part-time job with a full time (8 h), reporting that a 5 h working day could delay the development of some of the musculoskeletal disorders\(^16\). Although there is still a lack of evidence on how long exposure should be for the onset of musculoskeletal disorders in assembly lines\(^14,15\) it appears, among other variables, that the duration of the exposure (as a working time period) is critical for time of recovery.

Pauses or other job interruptions are supposed to allow the musculoskeletal system to recover, maintaining the worker productive and avoiding fatigue development\(^17\). Nevertheless, time variation, as the effects of duration, type, and frequency of rest periods are still poorly studied\(^8\), especially in employees working in assembly lines. Regarding the relationship between job interruptions and the effects on upper limb (UL) musculoskeletal symptoms and WRULMSD, there is even less evidence, being unclear whether there is any dependency between its’ length and the effect of a long-term period off, as a vacations’ period\(^18\).

The uncertainty surrounding the interactions between time in and out of work and the development of musculoskeletal disorders in high demanding jobs highlights the importance to follow workers with symptoms as a substantial measure to better understand work interactions and manage occupational health issues. This implies the assessment of early perceptions of pain, as musculoskeletal discomfort\(^3\), which has been reported as an initial stage of WRULMSD\(^3,19\)–\(^21\). Both musculoskeletal discomfort and pain are the most prevalent symptoms in work settings\(^22\) and its intensity should be related to changes in worker’s functional status\(^23\). Although there is no strong evidence regarding work context, musculoskeletal symptoms scoring intensity values over 4 in a 10-point scale have been established as significant and requiring intervention\(^22\). This is an important suggestion to take into account when we are referring to assembly lines work and to the management of workers’ health issues during working time periods.

Considering the insufficient evidence for the distribution, frequency and changes on intensity of the UL musculoskeletal symptoms over time\(^24,25\) in the automotive industry, the present study followed a group of assembly line workers during 7 months, before and after a 4-wk off period, with the specific aims: 1) to determine the potential effect of working time on the presence and intensity of upper limb musculoskeletal symptoms; 2) to verify the potential effect of 4 wk of job interruption in the upper limb musculoskeletal symptoms presence and intensity; 3) to describe the general health status and its relation to musculoskeletal symptoms intensity over time.

**Subjects and Methods**

**Study design**

This was a longitudinal study that followed assembly line workers from an automotive industry from September 2014 to April 2015, which included a job interruption of 4 wk for season holidays (between 15th December and 12th January). Data was initially assessed every month however, considering the interruption for holidays, the initial 6-month follow up turned into a 7-month longitudinal study. Considering this, data collection occurred in six different moments: three moments separated by one month before the 4-wk off period—T0 (baseline, September), T1 and T2, and three moments after the 4-wk off period (January, March and April—T3-T4-T5—respectively).

**Assembly line work**

In this area of the automotive industry, the car is assembled with other parts into a complete vehicle. The assembly line is divided into different areas; each area has a unit, constituted by different stations. In a typically 8 h’s working day, the worker changes to other station every 2 h. There are stations with powertools and handling devices, others requiring snap-fits (manual attachment of pre-shaped plastic flexible parts) and in several positions it is necessary to work under the car, above shoulder’s line. It is usual to acknowledge an assembly line as a workplace with noise, vibrations and machines, as vehicles of parts transport or garbage collection.

The cycle for a car to be assembled is short and that means that every 90 s a new car comes down to the line. The present industry had a morning shift (from 7.00 h to 15.30 h) and an evening shift (15.30 h to 23.00 h). The lunch/dinner break was of 30 min and for both shifts there were 2 additional breaks of 7 min each.

**Participants**

This study was in agreement with the recommendations
of the Declaration of Helsinki and submitted and accepted by the Portuguese Data Protection Authority (authorization nr 8602/2014). The workers attended an informative session to invite for participation. Individuals who agreed to participate signed an informed consent and provided their email address and number of employee.

Inclusion criteria were: (i) female and male workers, (ii) working at the assembly line, (iii) volunteers, (iv) age between 18 and 65 yr, (v) workers performing the same activity in the last 3 months, (vi) not having medical restrictions (as examples: not working with powertools, not performing movements above shoulder line or repetitive movements of the elbow joint).

There was no compensation for participating in this study; the company allowed the participation during working hours.

**Participant flow**

After the information session, there were 400 workers with intention to participate. From these, 270 completed the baseline survey (Fig. 1). After applying the inclusion criteria, only those participants whom completed the survey at least in one collection point besides T0 were selected (n=225) (Fig. 1).

The 225 workers considered in this study showed some fluctuations on their response during the follow-up period (Fig. 2). After 1 month, 2.2% did not answer to the survey and, in the last reply, a loss to follow up of 23.1% was found. This non response increased in time, although for T4 there was an exception.

**Outcomes**

For every collection points the work-related musculoskeletal symptoms (discomfort and pain), location and symptoms’ intensity were determined as the outcomes to analyze during the follow-up. A secondary outcome was general health status.

**Data collection**

Each point of follow up collected information through an online survey (SurveyMonkey.inc). The participants received by email a link to the questionnaire, which should be answered within 2 wk. If the participant failed to return a completed questionnaire within 10 d after the initial email, a second email with the questionnaire was sent. In the case of no response, a text message was sent to inform that the survey was closing in 24 h and the participation was important.

The survey was constituted by 5 topics at T0: 1- **sociodemographic data** (age, gender, weight, height), education, exercise – Do you perform regular physical exercise at least twice a week?); 2- **health data** (previous musculoskeletal injury – type and anatomical location of the injury, time of the last episode – diseases – Do you have any of the following diseases: a) Diabetes; b) Hypertension; c) Gout; d) Osteoporosis; e) Osteoarthritis; f) Herniated disc; g) Carpal tunnel syndrome; h) Other (please specify) – and medication data- Do you take any medication regularly?); 3- **self-reported general health status** (the first question of the Portuguese version of the 12-item short form Health Survey – SF-12:v2); 4- **work-related musculoskeletal symptoms** (presence of discomfort/pain – and its’ intensity and location); 5- **work-related information** (job designation, job tenure and perceived occupational risk hazards – yes/no. If the worker replied
“yes” to one or more hazards, the daily percentage was determined (Table 1). Answer as never/not applicable and 25% of the day were considered as low physical exposure, as the other possibilities were considered as high physical exposure.)

For the following data collection points—T1 to T5—the survey only collected the outcomes in study: the presence of musculoskeletal symptoms—discomfort/pain—and its intensity and location and the self-reported general health status.

Work-related UL musculoskeletal discomfort and pain

The presence of UL musculoskeletal symptoms was assessed considering a dichotomic question (yes/no answer) – At the present, or at least for 4 d during the last 7 d, have you experienced any musculoskeletal discomfort or pain? The temporal criteria had as referential the SALTSA criteria, a screening tool that takes into account the timeframe (symptoms at the present), duration (during at least 1 wk) and frequency (at least 4 d during the last 7 d)², 26).

Anatomical area and intensity of UL symptoms

A body map²⁷) was available with each data collection; the participants were expected to select the affected anatomical area. It was possible to select the right or left side of the body, and each body region was flagged (head, cervical, dorsal, lumbar, shoulder, arm, elbow, forearm, wrist, hand, hip, thigh, knee, leg, ankle, foot). Due to the heterogeneity and often multisite pain of the reported musculoskeletal symptoms in these settings²₈), in case there was more than one complaint the selection was to be based only on the highest intensity symptom.

For symptoms’ intensity, a 10-point scale was used—pain intensity numeric rating scale (PI-NRS)—where 0 represents “no pain” and 10 “unbearable pain”. This scale is easier to score and is validated to measure both pain and discomfort²⁹, 30), as was shown for sensitivity to changes in pain³¹, 32), reinforcing its use in reassessments and follow-up’s.

General health status

To analyze the dependency between the variations in general health status (GHS) and the symptoms’ intensity scores over time, GHS assessment was made through the first question of the Portuguese version of the 12-item short form SF-12³³) – How do you rate your overall current health? The workers should reply on a 5-point Likert scale ranging from 1 (excellent) to 5 (poor). This single global health-rating question has been previously used³⁴), considering a relation of the self-reported general health to chronic pain³⁵, 36).

Statistical methods

Descriptive statistics were used to describe the participants’ characteristics, as well as the outcomes during the follow-up (presence of symptoms, location and intensity).

Spearman’s rank correlation was used when analyzing the UL symptoms variations in time. To determine the UL symptoms’ mean intensity variation over the follow-up, a repeated-measures analysis of variance (ANOVA) was performed. An alpha level of 0.05 or less was accepted as statistically significant.

To study the outcomes presence of work-related UL symptoms and intensity during the 7 months, generalized estimating equations analysis was used³⁷, 38). Two models were determined: Model one, a logistic regression model, measured the effect of time (0, 1, 2, 4, 6, 7 months) on the outcome presence of work-related UL musculoskeletal symptoms (binary variable). The analysis was carried out with binomial distribution and a correlation structure autoregressive 1st order [AR (1)], with subjects measured repeatedly with time as repeated measures factor within subjects. For the effect estimates, odds ratio (OR) with corresponding 95% confidence intervals (CI) were reported.

In model two, a linear regression model measured the
effect of time (0, 1, 2, 4, 6, 7 months) on the intensity of work-related symptoms (numerical variable), with normal distribution, correlation structure autoregressive 1st order [AR (1)], with subjects measured repeatedly with time as repeated measures factor within subjects. The estimation of the effect considered the linear regression coefficient with corresponding 95% confidence intervals (CI).

All analyses were performed using the SPSS software (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY, USA).

Results

T0

Sociodemographic, health-data, self-reported job characteristics and self-reported musculoskeletal symptoms are listed in Table 2. The study population was mostly constituted by male workers (88.9%), predominantly in the age band 31–40 yr, with average job tenure of 15.49 yr.

There were 20.8% of the individuals reporting diseases. Among these, the majority selected other conditions (such as hearing problems, respiratory chronic conditions, associated conditions—as HTA with diabetes or asthma—gastritis, gout) or did not specify any disease. Regarding having a previous musculoskeletal injury, 57.8% of the workers answered yes, being the upper limb the most reported (20.4%). The last episode occurred at least 1 yr before the survey. The self-reported general health status was mainly stated as good (57.3%).

Regarding work characteristics, repetitive motion and force application, were the most selected (93.8 and 85.8%, respectively), both with high frequency of exposure/day (Table 2).

For work-related musculoskeletal symptoms, there were 68.4% of the participants reporting discomfort or pain at baseline, with mean intensity was 5.04 on the PI-NRS (Table 2). The majority of the reports considered the UL (35.6%) and the mean intensity was 5.31.

The follow-up study

Frequency of self-reported UL musculoskeletal symptoms

During the follow-up study the number of reported musculoskeletal symptoms had some variations. This was not statistical significant (p=0.072) and followed the loss of participations frequencies during the 7 months (Fig. 3).

The UL symptoms were the most frequently reported and increased significantly over time (p=0.001). Comparing the time points before and after the 4 wk off (T3) there was an increase of UL musculoskeletal symptoms immediately after the season holidays (Fig. 3).

Intensity of self-reported UL musculoskeletal symptoms

The mean intensity of the UL symptoms reported during the follow-up was always ≥5 in the PI-NRS scale (Fig. 4) (M=5.40, SD=2.08). The data collection after the 4-wk off (T3) was the time point with a higher value (M=5.5, SD=2.05).

During the study, there were statistical significant differences in intensity mean values (F1,1174=251.011, p<0.001).

Self-reported general health status and the association to UL symptoms

Over time, the general health status was mainly reported as “good”. It is possible to verify that after the vacations period both “very good” and “fair” categories increased (Fig. 5).

For all collection points, there was a significant positive association between the reported UL musculoskeletal symptoms and general health status (p<0.001). Considering symptoms’ intensity, the same positive and significant relations were found (p<0.001).

Time effect on work-related UL musculoskeletal symptoms and its intensity

Time had a statistical significant effect on having UL symptoms and on the intensity of the reported symptoms during the study (Table 3).

For having UL musculoskeletal symptoms the OR<1 shows a decrease of this outcome during time. Regarding the effect of time in the UL symptoms’ intensity, the GEE model shows an increase odds of 1.121 in symptoms intensity values (Table 3).

Discussion

The main goal of this study was to follow a group of workers during the course of 7 months, regarding the self-reported UL musculoskeletal symptoms presence and intensity and analyze the possible effects of 4 wk of holidays of the assembly line production.

As key points from the descriptive analysis there were several characteristics to consider, similar to other studies: participants were mostly men39–41), with an average age of 36 yr40, 42), the majority in the 16–20 yr of job tenure39, 43) and with a body mass index over 2540, 42–44).

This follow up showed that the variable time (as working time in the studied period) had a negative effect on UL musculoskeletal symptoms presence. The reported UL musculoskeletal symptoms increased after the 4-wk off. This goes in line with the cumulative effect of work in
the musculoskeletal system, considering that the temporal characteristics of the exposure—duration and dose—could be more important to the presence of symptoms\textsuperscript{14}). On the other side, the mean intensity of symptoms increased also after the 4 weeks of job interruption, showing a faint decrease after. This decrease is also present for the frequencies of reported UL symptoms and our GEE model shows this negative tendency during time (OR<1). It could be the case that if the follow up continued, the frequencies of musculoskeletal symptoms would be reduced.

Our results show that the expected positive effect from the 4-wk of absence from work was either short

Table 2. Baseline Characteristics

| Variable                           | N (%)   | Mean  | SD   |
|------------------------------------|---------|-------|------|
| Gender (male)                      | 200 (88.9) | ----- | ----- |
| Age (yr)                           |         | 36.20 | 4.99 |
| 18–20                              | 1 (0.4)  | ----- | ----- |
| 20–30                              | 22 (9.8) |       |      |
| 31–40                              | 164 (72.9) | ----- | ----- |
| 41–50                              | 37 (16.4) |       |      |
| >50                                | 1 (0.4)  |       |      |
| BMI                                | 25.44   | 3.33  |      |
| Normal (<25)                       | 109 (48.4) |       |      |
| Overweight (25–30)                 | 98 (43.6) | ----- | ----- |
| Obese (>30)                        | 18 (8)   |       |      |
| Education                          |         |       |      |
| Basic                              | 57 (25.3) | ----- | ----- |
| Upper Secondary                    | 153 (68)  |       |      |
| Higher School                      | 15 (6.7)  |       |      |
| Tenure (yr)                        |         | 15.49 | 5.92 |
| 0–5                                | 33 (14.7) |       |      |
| 6–10                               | 13 (5.8)  |       |      |
| 11–15                              | 21 (9.3)  | ----- | ----- |
| 16–20                              | 152 (67.5)|       |      |
| 21–25                              | 6 (2.7)   |       |      |
| Diseases (Yes)                     | 47 (20.8) |       |      |
| Diabetes                           | 1 (0.4)   |       |      |
| Hypertension                       | 7 (3.1)   |       |      |
| Other/NA                           | 39 (17.3) |       |      |
| Previous Musculoskeletal injury (Yes) | 130 (57.7) |       |      |
| Last episode                       |         |       |      |
| <1 yr                              | 39 (17.3) |       |      |
| 1–5 yr                             | 33 (14.7) |       |      |
| 6–10 yr                            | 14 (6.2)  |       |      |
| >10 yr                             | 16 (7.1)  |       |      |
| NA                                 | 28 (12.5) | ----- | ----- |
| Anatomical Area                    |         |       |      |
| Cervical                           | 5 (2.2)   |       |      |
| Lumbar                             | 20 (8.9)  |       |      |
| Upper limb                         | 46 (20.4) |       |      |
| Lower limb                         | 36 (16)   |       |      |
| Other/NA                           | 23 (10.2) |       |      |

SD: standard deviation; NA: no answer.

Table 2. Baseline Characteristics

| Variable                           | N (%)   | Mean  | SD   |
|------------------------------------|---------|-------|------|
| Medication (Yes)                   | 47 (20.9) |       |      |
| Regular Exercise (Yes)             | 112 (49.8) |       |      |
| General Health Status              |         |       |      |
| Excellent                          | 17 (7.6)  |       |      |
| Very good                          | 36 (16)   |       |      |
| Good                               | 129 (57.3) |       |      |
| Fair                               | 42 (18.7) |       |      |
| Poor                               | 1 (0.4)   |       |      |
| Manual Material Handling           |         |       |      |
| Low physical exposure (0 to 25% d) | 64 (28.4) |       |      |
| High physical exposure (50 to 100% d) | 68 (30.3) |       |      |
| Repetitive movement                | 211 (93.8) |       |      |
| Low physical exposure (0 to 25% d) | 34 (15.1)  |       |      |
| High physical exposure (50 to 100% d) | 177 (78.7) |       |      |
| Force application                  | 193 (85.8) |       |      |
| Low physical exposure (0 to 25% d) | 68 (30.2)  |       |      |
| High physical exposure (50 to 100% d) | 125 (55.6) |       |      |
| Static work                        | 177 (78.7) |       |      |
| Low physical exposure (0 to 25% d) | 70 (31.1)  |       |      |
| High physical exposure (50 to 100% d) | 107 (47.6) |       |      |
| Powertools                         | 122 (54.2) |       |      |
| Low physical exposure (0 to 25% d) | 37 (16.4)  |       |      |
| High physical exposure (50 to 100% d) | 85 (37.8)  |       |      |
| Musculoskeletal Symptoms (yes)     | 154 (68.4) |       |      |
| Intensity of symptoms (0–10)       | 5.04     | 2.07  |      |
| Upper limb musculoskeletal symptoms (yes) | 80 (35.6) |       |      |
| Intensity of symptoms (0–10)       | 5.31     | 1.2   |      |
Fig. 3. Number (N) of reported work-related musculoskeletal symptoms VS number (N) of work-related UL musculoskeletal symptoms during the follow-up.

Fig. 4. UL symptoms mean intensity during the study.

Fig. 5. Reported General Health Status of workers with UL symptoms.

Table 3. GEE analyses of the association between Time and a) having UL symptoms and b) UL symptoms intensity

|                        | B   | p-value | OR     | CI       |
|------------------------|-----|---------|--------|----------|
| Having UL symptoms     | 0.001 | 0.909   | 0.861–0.960 |
| UL Symptoms Intensity  | 0.115 | 0.008   | 1.121  | 1.031–1.220 |

OR: odds ratio; CI: 95% confidence interval Wald Test.
Having UL symptoms (yes/no).
UL symptoms (PI-NRS).
or inexistent (considering the number of reported UL symptoms and the decrease of workers with no symptoms both before and after the holidays) and for that its impact was not effective and enough to stop that progression. However, regarding the symptom intensity, it appears that the workers made an adaptation to work demands after the interruption. This could be due to the motor adaptation; a study on assembly lines work reported this adaptability as the capacity to modify when performing repetitive work. There are kinematic and kinetic changes of the upper limb, in response to muscle fatigue. Given that our study population can be determined as experienced, once the average years in the company is over 16, there is some evidence that for these type of workforce the ability to develop more variability for shorter cycles of work is higher. Additionally, it could be a hypothesis that in presence of chronic conditions, the return to work after the season holidays would be characterized by pain. After a musculoskeletal adaptation occurs, the symptoms would be decreasing (which can be explained by our GEE results).

Yet, the intensity of UL symptoms was always over 5 in the PI-NRS and the participants maintained their performance at work. This can reinforce the presence of chronic musculoskeletal diseases and persistent symptoms. Also the positive association of general health status and intensity of UL symptoms can support the relation of health status to chronic diseases. Regarding that these workers were still performing their job, besides an analysis on the cumulative effect of working days, the hypothesis of workers “neglecting their symptoms” is possible. The miss perception of the onset of pain as sudden and not gradual and the idea that experiencing symptoms is normal, are an example.

High-demand jobs are related to WRULMSD and there is existing evidence for the first occurrence of musculoskeletal disorders in the 3 to 6 months or in the first 12 months of newly employed workers. Taking this and the experienced workers in mind, we are excluding the hypothesis of new cases, once the fluctuations during time were mostly of workers with symptoms since T0 (and probably before). This is a situation already reported—workers with symptoms at baseline are more likely to have/maintain symptoms in follow-up studies.

To our knowledge, there is no consistent evidence considering a break of 4 wk and its impact on musculoskeletal symptoms in the automotive industry—studies have been reporting data concerning breaks during the workday or short vacations, as 2 wk, but in relation to well-being. As working time is strongly associated to the development of musculoskeletal disorders, it is still inaccurate to determine how long it takes to reduce an inflammation process or what would be the amount of time needed for recovery (and adaptation). The majority of the participants probably already had WRULMSD and the 4-wk off was not enough to reduce symptoms frequencies. A study on low back pain in high demanding jobs showed a cumulative effect of consecutive workdays and its relation to back pain. It can be hypothesized for our work population this cumulative effect and a similar result on the upper limb. A plausible justification can be related to WRULMSD development theories and the chronic inflammation process, that leads to changes over time. It can be predicted that the symptoms reported would be more related to an inflammatory episode of chronic pain rather to an acute injury, even though this is still a multivariable and complex transition.

Furthermore, given the fact that the reported UL musculoskeletal symptoms in our study had high intensity values, we consider that it was in fact musculoskeletal pain rather than discomfort, since the latter is likely to be reversed by load reduction or rest.

**Study limitations**

This study had several limitations and our findings have limited transferability to other automotive assembly lines. Firstly, these were volunteer workers and that could represent a sample bias. Secondly, the outcomes in study were exclusively based on self-reported information that could determine possible misclassification bias or/and underestimation of the associations. A physical assessment in each collection point would be important to overcome this limitation. Thirdly, after the 4-wk off the number of participants dropped 19.6%, contrary to the increase of UL symptoms. Considering the self-reported data, follow up studies can lead to bias, once there is a higher probability of maintain the workers with health complaints. It is also a fact that the 7-month follow up is, by itself, a limitation, once we can question if this time period was enough to understand the development of the UL symptoms over time. Perhaps a longer study, with other season holidays break, would add important information in this topic.

**Recommendations**

We consider important in the future to develop more studies on job daily rotations in automotive assembly lines, once it can contribute to the cumulative exposure of the upper limbs. One hour rotation, which is not the cur-
rent rotation system for these type of industries\textsuperscript{56}, could be more appropriate to muscle activity patterns\textsuperscript{16}. Also studies on new approaches in the return to high demanding jobs after sickness leave or holidays would be of must importance in chronic musculoskeletal conditions. This highlights the importance of the reorganization of work in high demanding jobs, in order to prevent WRULMSD. Additionally, to be able to follow workers through time can provide important evidence to better understand the transitions between muscle fatigue, musculoskeletal discomfort and pain\textsuperscript{3}).

**Availability of Data and Material**

All data analyzed during this study are included in this published article.

**Authors’ Contributions**

All authors contributed to the development of this study. All authors participated in revising the article critically for important intellectual content; all authors gave final approval of the version to be submitted.

**Conflict of Interest**

The authors of this manuscript declare that they have no conflicting interests, financially or non-financially.

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**References**

1) Sluiter JK (2006) High-demand jobs: age-related diversity in work ability? Appl Ergon 37, 429–40. [Medline] [CrossRef]

2) Sluiter JK, Rest KM, Frings-Dresen MH (2001) Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. Scand J Work Environ Health 27 Suppl 1, 1–102. [Medline] [CrossRef]

3) Madeleine P (2010) On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. Acta Physiol (Oxf) 199 Suppl 679, 1–46. [Medline] [CrossRef]

4) Nordander C, Ohlsson K, Åkesson I, Arvidsson I, Balogh I, Hansson GÅ, Strömberg U, Rittner R, Skerfving S (2013) Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands—a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 44, 241–53. [Medline] [CrossRef]

5) Qin J, Lin JH, Faber GS, Buchholz B, Xu X (2014) Upper extremity kinematic and kinetic adaptations during a fatiguing repetitive task. J Electromyogr Kinesiol 24, 404–11. [Medline] [CrossRef]

6) Yung M, Bigelow PL, Hastings DM, Wells RP (2014) Detecting within- and between-day manifestations of neuromuscular fatigue at work: an exploratory study. Ergonomics 57, 1562–73. [Medline] [CrossRef]

7) Bernard B (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, 2nd Ed., 590, National Institute for Occupational Safety and Health, Cincinnati.

8) Wells R, Mathiassen SE, Medbo L, Winkel J (2007) Time—a key issue for musculoskeletal health and manufacturing. Appl Ergon 38, 733–44. [Medline] [CrossRef]

9) Sadi J, MacDermid JC, Chesworth B, Birmingham T (2007) A 13-year cohort study of musculoskeletal disorders treated in an autoplant, on-site physiotherapy clinic. J Occup Rehabil 17, 610–22. [Medline] [CrossRef]

10) Sancini A, Capozzella A, Caciar T, Tomei F, Nardone N, Scala B, Fiaschetti M, Cetica C, Scimitto L, Gioffrè P, Sinibaldi F, Di Pastena C, Corbosiero P, Schifano MP, Tomei G, Ciarrocca M (2013) Risk of upper extremity biomechanical overload in automotive facility. Biomed Environ Sci 26, 70–5. [Medline]

11) Spallek M, Kuhn W, Uibel S, van Mark A, Quarcoo D (2010) Work-related musculoskeletal disorders in the automotive industry due to repetitive work—implications for rehabilitation. J Occup Med Toxicol 5, 6. [Medline] [CrossRef]

12) Hagberg M, Violante FS, Bonfiglioli R, Descatha A, Gold J, Evanoff B, Sluiter JK (2012) Prevention of musculoskeletal disorders in workers: classification and health surveillance—statements of the Scientific Committee on Musculoskeletal Disorders of the International Commission on Occupational Health. BMC Musculoskelet Disord 13, 109. [Medline] [CrossRef]
21) Marley RJ, Kumar N (1996) An improved musculoskeletal discomfort assessment tool. Int J Ind Ergon 17, 21–7. [CrossRef]
22) Werner RA, Franzblau A, Bellamy N, Ulm S, Armstrong TJ (2005) A longitudinal study of industrial and clerical workers: predictors of upper extremity tendinitis. J Occup Rehabil 15, 37–46. [Medline] [CrossRef]
23) Stigmar KG, Petersson IF, Jöud A, Grahn BE (2013) Promoting work ability in a structured national rehabilitation program in patients with musculoskeletal disorders: outcomes and predictors in a prospective cohort study. BMC Musculoskelet Disord 14, 57. [Medline] [CrossRef]
24) Kennedy CA, Amick BC 3rd, Dennerlein JT, Brewer S, Catli S, Williams R, Sera C, Gerr F, Irvin E, Mahood Q, Franzblau A, Van Eerd D, Evanoff B, Rempel D (2010) Systematic review of the role of occupational health and safety interventions in the prevention of upper extremity musculoskeletal symptoms, signs, disorders, injuries, claims and lost time. J Occup Rehabil 20, 127–62. [Medline] [CrossRef]
25) Zoer I, Frings-Dresen MHW, Sluiter JK (2014) Are musculoskeletal complaints, related work impairment and desirable adjustments in work age-specific? Int Arch Occup Environ Health 87, 647–54. [Medline] [CrossRef]
26) Aublet-Cuvelier A, Ha C, Roquelaure Y, D’Escatha A, Meyer JP, Sluiter JK, Frings-Dresen MH, Rest KM (2010) Protocole d’examen clinique pour le dépistage des troubles musculosquelettiques du membre supérieur Adaptation française du consensus européen SALTSA. INRS, Montreal.
27) Petty N, Moore AP (2004) Principles of neuromusculoskeletal treatment and management. Churchill Livingstone, London.
28) Parot-Schinkel E, Descatha A, Ha C, Petit A, Leclerc A, Roquelaure Y (2012) Prevalence of multisite musculoskeletal symptoms: a French cross-sectional working population-based study. BMC Musculoskelet Disord 13, 122. [Medline] [CrossRef]
29) Johnson C (2005) Measuring pain. Visual analog scale versus numeric pain scale: what is the difference? J Chiropr Med 4, 43–4. [Medline] [CrossRef]
30) Dworkin RH, Turk DC, Farrar JT, Haythornthwaite JA, Jensen MP, Katz NP, Kerss RD, Stucki G, Allen RR, Bellamy N, Carr DB, Chandler J, Cowan P, Dionne R, Galer BS, Hertz S, Jadad AR, Kramer LD, Manning DC, Martin S, McCormick CG, McDermott MP, McGrath P, Quessy S, Rappaport BA, Robbins W, Robinson JP, Rothman M, Royal MA, Simon L, Stauffer JW, Stein W, Tollett J, Wernicke J, Witter J, IMMPACT (2005) Core outcome measures for chronic pain clinical trials: IMMPACT recommendations. Pain 113, 9–19. [Medline] [CrossRef]
31) Ritter PL, González VM, Laurent DD, Lorig KR (2006) Measurement of pain using the visual numeric scale. J Rheumatol 33, 574–80. [Medline]
32) Salaffi F, Ciapetti A, Carotti M (2012) Pain assessment strategies in patients with musculoskeletal conditions. Reumatismo 64, 216–29. [Medline] [CrossRef]
33) Cunha-Miranda L, Vaz-Patto J, Micaelo M, Teixeira A, Silva C, Saraiva-Ribeiro J FSG (2010) The 12-Item Short Form Health Survey (SF-12:v2), Validação da escala para uso em Portugal Resultados do FRAIL Study. Acta Reumatol. Port.
34) Sundstrup E, Jakobsen MD, Brandt M, Jay K, Aagaard P, Andersen LL (2016) Associations between biopsychosocial factors and chronic upper limb pain among slaughterhouse workers: cross sectional study. BMC Musculoskelet Disord 17, 104. [Medline] [CrossRef]
35) Turk DC, Dworkin RH, Allen RR, Bellamy N, Brandenburg N, Carr DB, Cleeland C, Dionne R, Farrar JT, Galer BS, Hewitt DJ, Jadad AR, Katz NP, Kramer LD, Manning DC, McCormick CG, McDermott MP, McGrath P, Quessy S, Rappaport BA, Robinson JP, Royal MA, Simon L, Stauffer JW, Stein W, Tollett J, Witter J (2003) Core outcome domains for chronic pain clinical trials: IMMPACT recommendations. Pain 106, 337–45. [Medline] [CrossRef]
36) Koolhaas W, van der Klink JJ, de Boer MR, Groothoff
37) Azuero A, Pisu M, McNees P, Burkhardt J, Benz R, Meneses K (2010) An application of longitudinal analysis with skewed outcomes. Nurs Res 59, 301–7. [Medline] [CrossRef]

38) Driessen MT, Anema JR, Proper KI, Bongers PM, van der Beek AJ (2008) Stay@Work: participatory ergonomics to prevent low back and neck pain among workers: design of a randomised controlled trial to evaluate the (cost-)effectiveness. BMC Musculoskelet Disord 9, 145. [Medline] [CrossRef]

39) Ohlander J, Keskin MC, Weiler S, Stork J, Radon K (2016) Snap-fits and upper limb functional limitations in German automotive workers. Occup Med (Lond) 66, 471–7. [Medline] [CrossRef]

40) Valirad F, Ghaffari M, Abdi A, Attarchi M, Mircheraghi SF, Mohammadi S (2015) Interaction of physical exposures and occupational factors on sickness absence in automotive industry workers. Glob J Health Sci 7, 276–84. [Medline] [CrossRef]

41) Menegon FA, Fischer FM (2012) Musculoskeletal reported symptoms among aircraft assembly workers: a multifactorial approach. Work 41 Suppl 1, 3738–45. [Medline] [CrossRef]

42) Landau K, Rademacher H, Meschke H, Winter G, Schaub K, Grasmueck M, Moelbert I, Sommer M, Schulze J (2008) Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects. Int J Ind Ergon 38, 561–76. [CrossRef]

43) Ohlander J, Keskin MC, Weiler SW, Stork J, Radon K (2019) Snap-fit assembly and upper limb functional limitations in automotive production workers: a nested case-control study. Int Arch Occup Environ Health 92, 813–9. [Medline] [CrossRef]

44) Sihawong R, Sitthipornvorakul E, Paksachol A, Janwantanakul P (2016) Predictors for chronic neck and low back pain in office workers: a 1-year prospective cohort study. J Occup Health 58, 16–24. [Medline] [CrossRef]

45) Gilles MA, Guélin JC, Desbrosses K, Wild P (2017) Motor adaptation capacity as a function of age in carrying out a repetitive assembly task at imposed work paces. Appl Ergon 64, 47–55. [Medline] [CrossRef]

46) Hunter D, Silverstein B (2014) Perceptions of risk from workers in high risk industries with work related musculoskeletal disorders. Work 49, 689–703. [Medline] [CrossRef]

47) Gardner BT, Dale AM, VanDillen L, Franzblau E, Evanoff BA (2008) Predictors of upper extremity symptoms and functional impairment among workers employed for 6 months in a new job. Am J Ind Med 51, 932–40. [Medline] [CrossRef]

48) Januario LB, Madeleine P, Cid MM, Samani A, Oliveira AB (2018) Can exposure variation be promoted in the shoulder girdle muscles by modifying work pace and inserting pauses during simulated assembly work? Appl Ergon 66, 151–60. [Medline] [CrossRef]

49) Brewer S, Van Eerd D, Amick BC 3rd, Irvin E, Daum KM, Gerr F, Moore JS, Cullen K, Rempel D (2006) Workplace interventions to prevent musculoskeletal and visual symptoms and disorders among computer users: a systematic review. J Occup Rehabil 16, 325–58. [Medline] [CrossRef]

50) Punnett L (2014) Musculoskeletal disorders and occupational exposures: how should we judge the evidence concerning the causal association? Scand J Public Health 42 Suppl, 49–58. [Medline] [CrossRef]

51) Andersen LL, Fallentin N, Ajlslev JZN, Jakobsen MD, Sundstrup E (2017) Association between occupational lifting and day-to-day change in low-back pain intensity based on company records and text messages. Scand J Work Environ Health 43, 68–74. [Medline] [CrossRef]

52) Barr AE, Barbe MF (2002) Pathophysiological tissue changes associated with repetitive movement: a review of the evidence. Phys Ther 82, 173–87. [Medline] [CrossRef]

53) Barr AE, Barbe MF (2004) Inflammation reduces physiological tissue tolerance in the development of work-related musculoskeletal disorders. J Electromyogr Kinesiol 14, 77–85. [Medline] [CrossRef]

54) Santos HG, Chiavegato LD, Valentim DP, da Silva PR, Padula RS (2016) Resistance training program for fatigue management in the workplace: exercise protocol in a cluster randomized controlled trial. BMC Public Health 16, 1218. [Medline] [CrossRef]

55) Mann CJ (2003) Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emerg Med J 20, 54–60. [Medline] [CrossRef]

56) Graham RB, Agnew MJ, Stevenson JM (2009) Effectiveness of an on-body lifting aid at reducing low back physical demands during an automotive assembly task: assessment of EMG response and user acceptability. Appl Ergon 40, 936–42. [Medline] [CrossRef]