Development of fatigue and discomfort in the upper trapezius muscle during light manual work

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Optimization of the temporal aspects of task design requires a better understanding of the development of muscle fatigue in the neck and shoulder region over time. The objective of the study was to investigate this in two production companies and to determine the relationship between objective and subjective estimates of fatigue. Indicators of fatigue were obtained through electromyography (EMG) during test contractions and ratings of perceived discomfort. EMG amplitude increased during the day in both case studies while mean power frequency decreased only in one case. In both cases, a more detailed frequency analysis of the EMG signals showed an increase in lower frequency power accompanied by a decrease in higher frequency power. Local perceived discomfort in the neck and shoulder increased over the course of the day in both cases. However, no clear relationship between perceived discomfort and objective indicators of fatigue was found. Obtaining sufficient sensitivity to detect effects of temporal aspects of task design probably requires complementary or more refined methods (e.g. EMG arrays, mechanomyography).

Keywords: Muscle fatigue; Light manual work; Electromyography

1. Introduction

Work-related musculoskeletal disorders are common in industrial workplaces and contribute considerably to absenteeism (Sluiter *et al.* 2001, Buckle and Devereux 2002, Walker-Bone and Cooper 2005). A number of studies have identified occupational risk factors that are associated with musculoskeletal disorders. In particular, repetitive movements, high velocity and acceleration of movements, high external forces, prolonged static load on the muscles and extreme working postures are considered physical work-related risk factors (e.g. Kilbom 1994, Bernard 1997, Hägg 2000). It is, however, remarkable that work-related upper extremity disorders also occur in the

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absence of high force exertion and awkward body postures (National Research Council and Institute of Medicine 2001, Andersen *et al.* 2003). Even very low muscle strains in terms of the load intensity (1–2% maximal voluntary contraction (MVC)) are sometimes associated with elevated rates of occupational disorders (Aarås 1994). Light-assembly work is a clear example of low intensity work with elevated risks of neck and shoulder disorders (Aarås and Westgaard 1987, Hagberg and Wegman 1987, Mathiassen *et al.* 1993).

In general, preventive measures concerning physical risk factors have been focused on reducing the intensity of musculoskeletal loads. Positive effects of load intensity-reducing measures, such as workstation redesign, have been described (McKenzie *et al.* 1985, Erisman and Wick 1992). Other studies, however, show that neck and shoulder disorders are rather impervious to work station improvements (Winkel and Oxenburgh 1990). If workstations are well designed and work intensity is low, strategies affecting the temporal pattern of the load might be more effective. These may concern the length of the working day, the work pace, the work – rest scheme or variations in tasks (Mathiassen and Winkel 1996). Questions about the optimal temporal pattern with regard to performance and health for low-intensity work situations are for the greater part unanswered.

Several studies show that muscle fatigue is an important initiating factor in the development of neck and shoulder muscle disorders (Bjelle *et al.* 1981, Rempel *et al.* 1992, Sundelin and Hagberg 1992, Takala 2002). Therefore, muscle fatigue, when measured during work, may provide a relevant biomarker for cumulative exposure to repetitive work (Dennerlein *et al.* 2003). In order to define the optimal time pattern of the work, a good understanding of the development of muscle fatigue over the course of a working day might be helpful.

The development of muscle fatigue at repetitive, low-intensity tasks has been studied on the basis of objective measurements (mainly electromyography (EMG)) and subjective rating scales.

In a laboratory study by Sundelin and Hagberg (1992), subjects performed a pick and place task for 1 h with their right arm. An increase in amplitude and a decrease in frequency content of the trapezius muscle EMG was found, while subjective ratings of fatigue in the shoulder muscle significantly increased. Moreover, a significant relationship between subjective and objective measurements of muscle fatigue was found. However, it remains unknown how muscle fatigue develops over longer working periods and whether the relationship between objective and subjective measurements of muscle fatigue holds for longer periods interspersed with (short) rest breaks.

Suurküla and Hägg (1987) investigated the development of muscle fatigue in the trapezius and infraspinatus muscles after 2 h working at the workplace. EMG variables showed a trend towards fatigue, but this was not statistically tested. Mathiassen and Winkel (1996) studied the assembly of starters of power saws. In a laboratory setting, they also found a trend towards increased muscle fatigue in the trapezius muscle over the course of a simulated 6-h working day (with a 10% increase of amplitude and a 2.5% decrease in frequency content) but these changes were only partially significant. Perceived fatigue increased significantly during the working day. No clear statements were made about the relationships between the objective and subjective measurements.

Bennie *et al.* (2002) and Dennerlein *et al.* (2003) investigated an isolated repetitive ulnar deviation task at a low intensity level during a simulated 8-h working day. Electrostimulation and EMG measurements of the extensor carpi ulnaris were used to

detect muscle fatigue. A subjective rating scale was used to investigate the development of local perceived discomfort. Both objective measurements showed an increase in muscle fatigue over the course of an 8-h working day in the absence of perceived fatigue.

In summary, the development of muscle fatigue in realistic working tasks has only received a little attention. Controversies remain on changes in objective and subjective fatigue indicators as well as on their relationship.

In the present paper, two case studies are described that were performed at two different assembly companies. In the first case, subjects worked for 4 weeks with normal 8-h working days and 4 weeks with extended 9.5-h working days. In the second case, employees worked 1 week with a 9-h working day. The general questions that both studies tried to answer were:

- how do objective estimates of muscle fatigue in the neck and shoulder region develop over a working day during repetitive low-intensity assembly work in a real-life occupational setting?
- how do objective estimates of fatigue relate to subjective feelings of local discomfort during low-intensity work?

In addition two specific questions were investigated:

1. How does muscle fatigue develop during an 8-h working day compared to the fatigue development during a 9.5-h working day (case study 1)?
2. Is there a difference in the development of muscle fatigue on the first day of the week compared with the last day (case study 2)?

2. Method

2.1. *Case study 1*

The first case study was carried out in a production unit of a Dutch manufacturer of medical instruments. Ten subjects (four males and six females) participated in the study. Table 1 shows the demographics of the sample. None of the subjects reported any musculoskeletal disorders. All subjects were experienced assemblers (with 5.7 ± 1.0 years of experience). The subjects gave their written informed consent prior to the start of the study.

These subjects assembled catheters by picking and placing small parts (figure 1a,b). They also performed the quality control for their own work by visual inspection. The

Table 1. Demographics of the samples in the case studies.

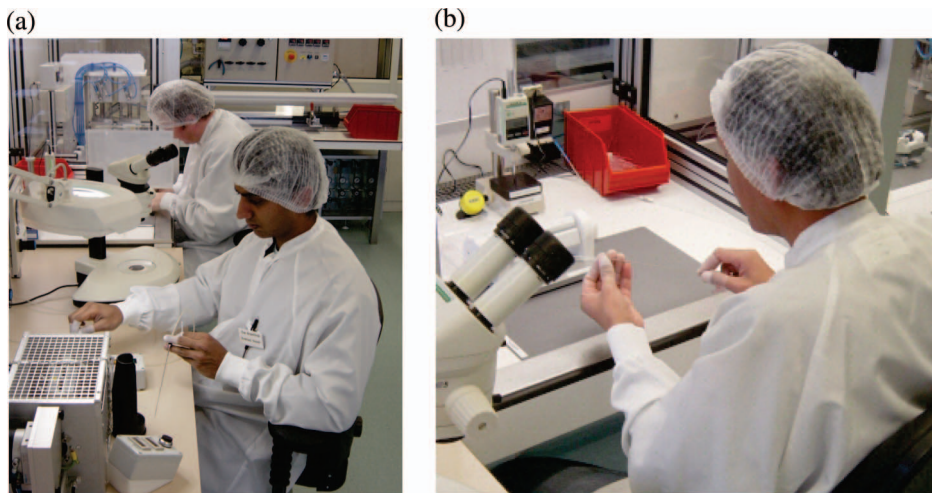|	Case study 1			Case study 2		
	Range	Mean	SD	Range	Mean	SD
Age (years)	25–52	38.5	8.0	37–46	42.1	2.6
Stature (cm)	160–190	161.8	10.7	160–172	166.3	4.4
Weight (kg)	58–98	69.3	12.5	62–100	74.5	13.0
BMI (kg/m^2)	20–33	24.5	3.4	21–37	26.8	5.4

(a) (b)

Figure 1. (a) A double workstation for the assembly of catheters; (b) detailed view of the production of catheters in case study 1.

work was monotonous, low-intensity with static neck postures and repetitive arm lifting. There was no regular task rotation. Workers were not paced by a driven production line, but worked at single or coupled workstations. The work pace was indirectly defined by a target (products per hour), but employees were free to take micro-breaks during the day. The intensity of the trapezius muscle load was not measured during the task but was estimated at 5% MVC.

The subjects first worked 8 h per working day for a period of 4 weeks (normal days) followed by a 4-week period of working days of 9.5 h (extended days). The day started at 07.00 hours and ended at 15.30 hours and 17.00 hours respectively in the two periods. Two coffee breaks of 15 min were taken on normal days. On the extended working days, one 15-min coffee break was taken in the morning and two 10 min breaks were taken in the afternoon. There was a standard 30 min lunch break.

Measurements (described below) took place in the fourth week of the normal and the extended working day periods.

2.2. Case study 2

The second study took place at a Dutch manufacturer of shavers. A group of ten female subjects participated in the study. None of the subjects reported musculoskeletal disorders. All subjects were experienced assemblers. The subjects gave their written informed consent at the start of the study. Table 1 shows the demographics of the sample.

The study took place on a driven production line where shavers were painted automatically. Production-line workers put on and removed small covers with a frequency of 18 movements/min (figure 2). The work pace was determined by the speed of the sprayer. Natural micro-breaks were possible but people were not allowed to walk away. Workers rotated between workstations every hour, but the kind of activity did not change. A static neck posture and repetitive arm lifting were the most important characteristics of the workers' physical load. The work intensity on the trapezius muscle was not directly

measured but was similar to previous data (e.g. Mathiassen and Winkel 1996) and was estimated at 15% MVC.

The subjects worked for 1 week with 9-h working days. The day started at 14.00 hours and ended at 23.30 hours. Subjects had a short 10 min break every hour. There was a lunch break of 30 min. Measurements took place on Monday and Friday.

2.3. *Measurements*

2.3.1. Electromyography. A standard isometric test contraction with a duration of 30 s (Suurküla and Hägg 1987) was performed while the subjects sat at their own work chairs and held their arms abducted at shoulder height at an angle of 90° (figure 3). The position of the arms was controlled by horizontal flexible rods on stands.

Muscle activity was measured by means of surface EMG (porti 16/ASD system; TMS, Enschede, The Netherlands). Bipolar Ag/AgCl (Medicotest, Ambu A/S, Baltorpbakken 13, DK-2750 Ballerup) surface electrodes were placed with an
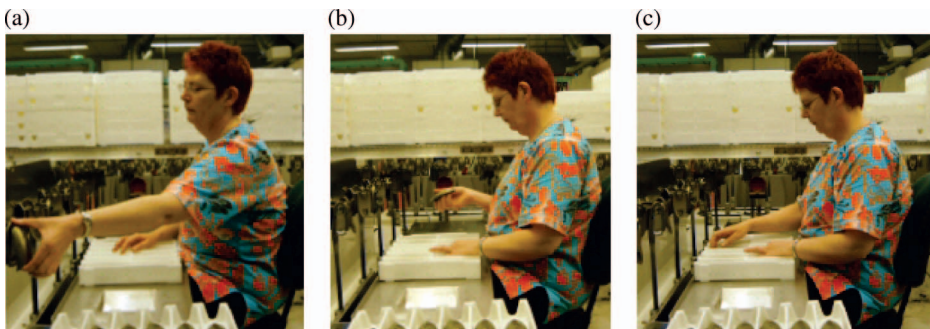

Figure 2. Detailed view of the assembly task in case study 2. (a) Picking the product; (b) visual control; (c) placing the product.

Figure 3. The electromyography test contraction.

interelectrode distance of 25 mm at the trapezius pars decendens muscles. The electrode positions were located according to Hermens *et al.* (2000). Electrode placement was controlled by an elastic cord. New electrodes were applied each working day. A reference electrode was placed on the C7 spinous process. Before the electrodes were applied, the skin was shaved, scrubbed and cleaned with alcohol. Skin resistance was not measured. Raw EMG signals were sampled during the test contraction with a sample frequency of 1000 Hz and band-pass filtered (10–400 Hz).

Mean amplitude was calculated by rectifying and low pass filtering (2 Hz) the EMG signal. The amplitude values were normalized to the EMG values measured during the test contraction at the start of the working day. The mean power frequency (MPF) was analysed using a fast Fourier transformation with a sliding window of 1000 samples with a 500 sample overlap between consecutive windows. The MPF values were normalized to the measurement at the beginning of the working day. Using the power spectra, six frequency bands of 50 Hz were used to analyse the frequency content in more detail (Dolan *et al.* 1995). The first band was 10–50 Hz, the next 50–100 Hz and so on, up to 300 Hz.

The mean power of each band was calculated. The relative power of each band in relation to the total power was determined by dividing the mean power of each band by the total power.

2.3.2. Discomfort. Discomfort was measured using the local perceived discomfort method (van der Grinten 1991). A body map consisting of four regions in the neck and shoulder was presented to the subjects. Subjects were asked to rate discomfort in the regions identified on a 10 point-scale (ranging from $0 =$ no discomfort to $10 =$ extreme discomfort, almost maximum). The highest discomfort score in the four regions was defined as the score for discomfort.

In the first case study, EMG and discomfort measurements were performed four times on both days (before starting, before and after the lunch break and at the end of the day). On the extended day an extra measurement was made at the end of the eighth hour. The schedule of discomfort measurements is shown in figure 4a,b.

In the second case study, measurements were obtained before the beginning of the day's work, before and after the lunch break and at the end of the working day (as shown in figure 4c).

2.4. *Statistical analysis*

Data were analysed with a repeated measures ANOVA to compare the independent variables (days (2) and time moments (4)) for all dependent variables (EMG MPF, amplitude, relative power in each frequency band and local perceived discomfort). Two additional ANOVA were used to evaluate the effects on the relative power in each frequency band for the separate daily periods (before lunch and after lunch). *p*-Values were based on degrees of freedom corrected with Greenhouse-Geisser's epsilon to compensate for the effects of violations of the sphericity assumption. A Student t-test was used as the follow-up test for comparisons of means. On the normal working day of the first case study, two EMG measurements were missing (for two different subjects). Missing values were replaced by using the mean relative change of the whole group. Pearson's product moment correlation was calculated to determine the relationships between objective EMG variables and discomfort. Significance was accepted at $p < 0.05$.
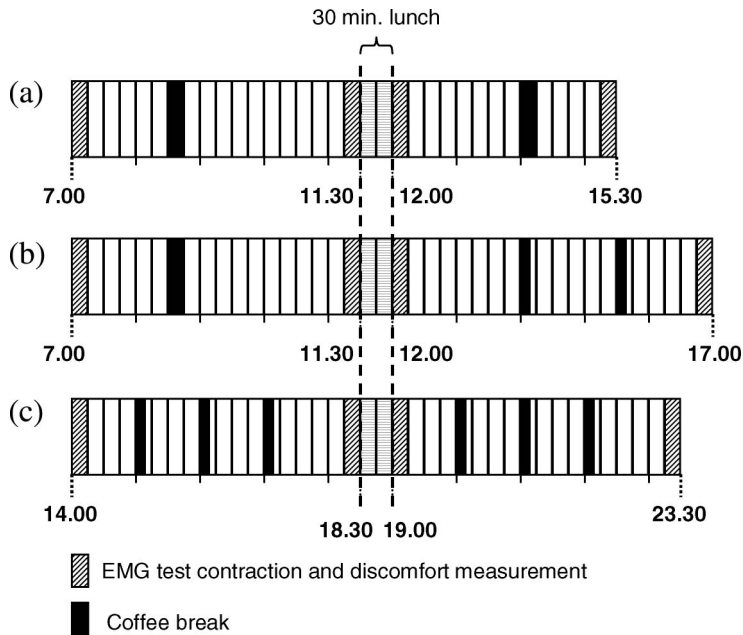
Figure 4. (a) The normal working days in case study 1; (b) the extended working days in case study 1; (c) the working days in case study 2. EMG = electromyography.

3. Results

3.1. *Mean power frequency and amplitude of the electromyography: case study 1*

In case study 1, no significant temporal changes in the MPF were found (figure 5a). Furthermore, there were no significant differences in the relative changes of the MPF between the normal and the extended working days ($p = 0.211$). For the amplitude of the EMG signal, a main effect of time was found ($p = 0.007$). A post-hoc test revealed a significant increase in the first period of the day ($p = 0.005$). The amplitude did not change over lunch or the second period of the day. There were no significant differences in the relative changes in amplitude ($p = 0.203$) found between the normal and the extended working days (figure 5b).

3.2. *Mean power frequency and amplitude of the electromyography: case study 2*

In case study 2, a significant temporal change in the MPF was found ($p = 0.021$). A post-hoc test showed that the MPF decreased in the period before lunch ($p = 0.021$). The increase of the MPF during the lunch period, which may have indicated muscle recovery, was not significant (figure 6a). A main effect of time was also found for the amplitude of the EMG ($p = 0.014$). A post-hoc test revealed a significant increase in the first period ($p = 0.011$). Other temporal changes during the working day were not significant (figure 6b).

With regard to the development of fatigue over the working week, the relative decreases of the MPF and the relative increases in amplitude on both working days did not differ significantly.

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(a)
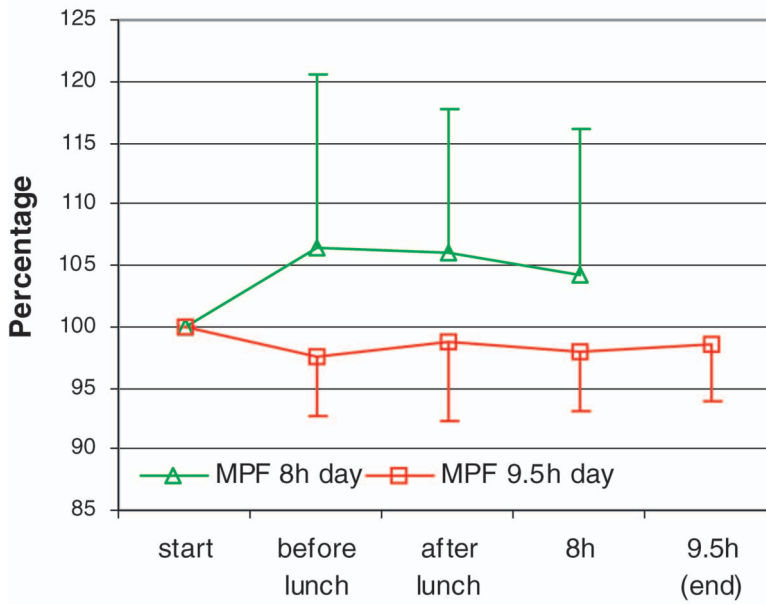
(b)

Figure 5. (a) The relative changes in the mean power frequency (MPF) in case study 1 for the extended and normal working days; (b) the relative changes in electromyography amplitude during the extended and normal working days in case study 1. Bars represent SD.
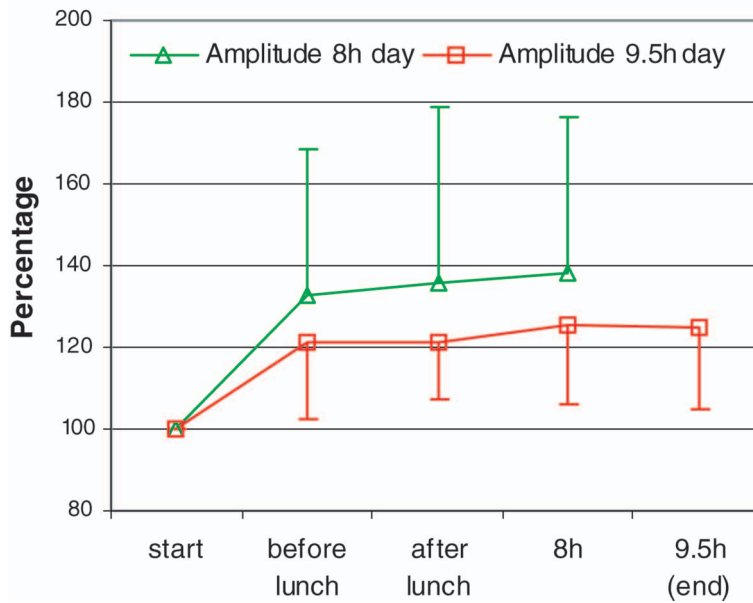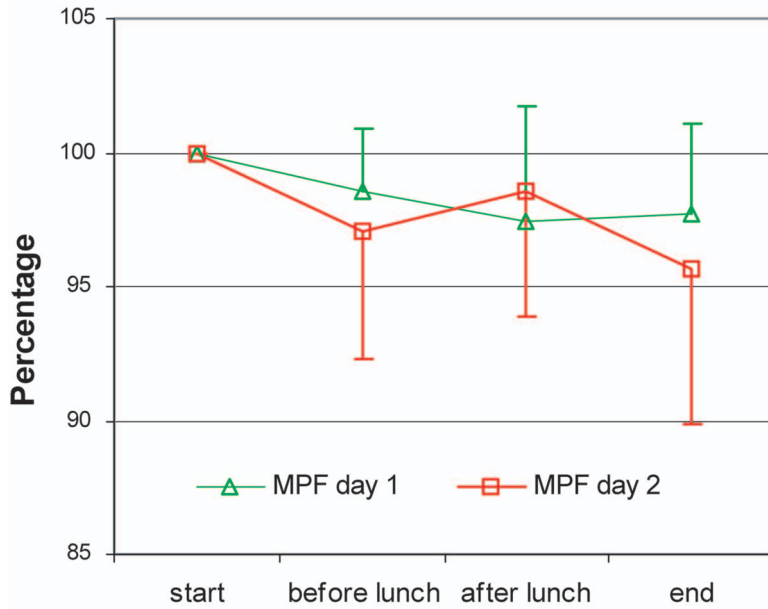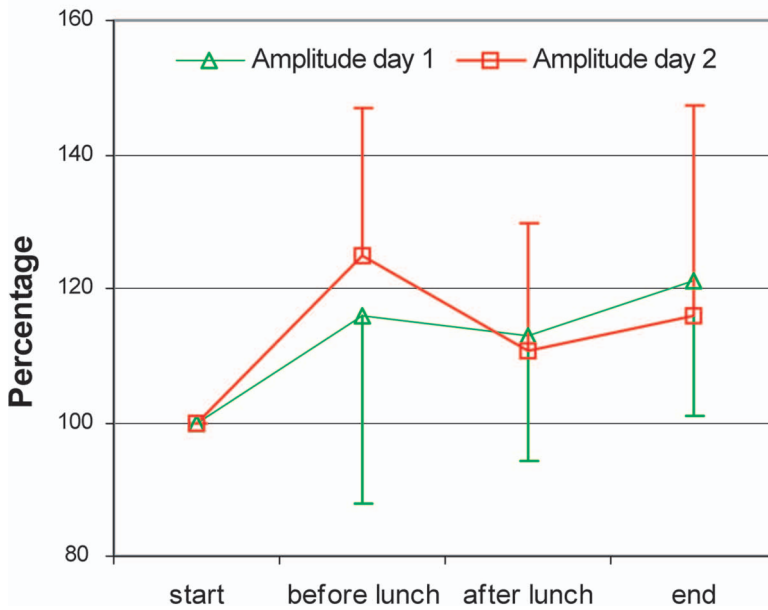
Figure 6. (a) The relative changes in the mean power frequency (MPF) in case study 2 for the first and last days of the week; (b) the relative changes in electromyography amplitude during the working days in case study 2. Bars represent SD.

3.3. *Frequency banding*

If muscle fatigue is present, an increase in lower frequency bands and a decrease in higher frequency bands over the course of a working day is expected. However, an ANOVA with measurement time and frequency band did not show a significant interaction between the relative power in frequency bands and time for either day in case study 1. An additional ANOVA was used to investigate the change over time separately for the periods before and after lunch. On the extended working days, the relative power of the lower frequencies increased significantly ($p = 0.033$) accompanied by a significant reduction of higher frequencies ($p = 0.008$). No other significant temporal changes were found (figure 7).

In case study 2 (figure 8), a significant interaction between frequency band and time was found on the second working day ($p = 0.023$). A post-hoc test showed an increase in relative power ($p = 0.05$) in the lower frequency band (10–50 Hz) in the period after lunch accompanied by a significant reduction ($p = 0.001$) of relative power of the higher frequencies (100–150 Hz). In the first period of the second working day, the increase in power of the lower frequencies (10–50 Hz) was not significant but a trend to an increase in power existed ($p = 0.08$). The decrease of the higher frequencies was, on the other hand, significant ($p = 0.018$). There were no significant interactions found on the first day of the week.
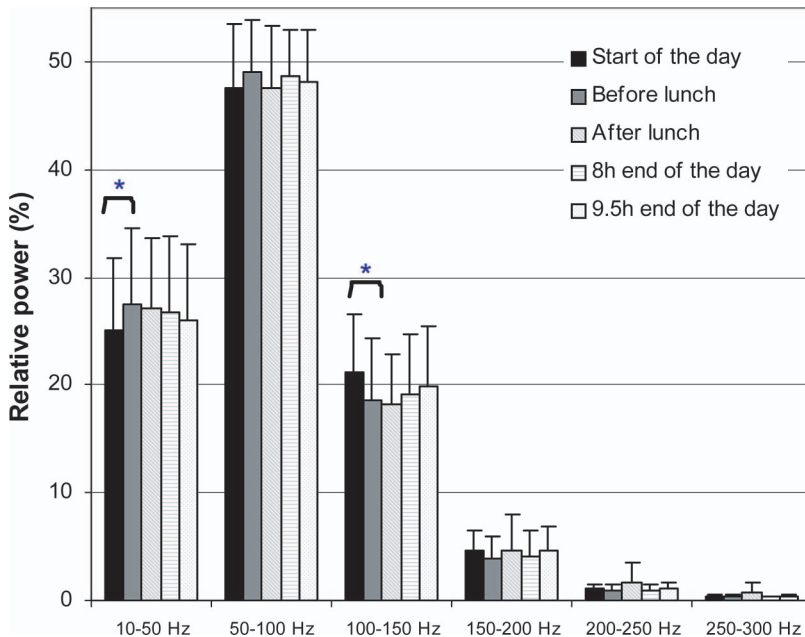

Figure 7. Relative power of each frequency band in relation to the total power on the extended working day of the first case study. The low frequency band (10–50 Hz) significantly increased before the lunch, which was accompanied by a significant decrease in higher frequencies (150–200 Hz), indicated by *. Bars represent SD.
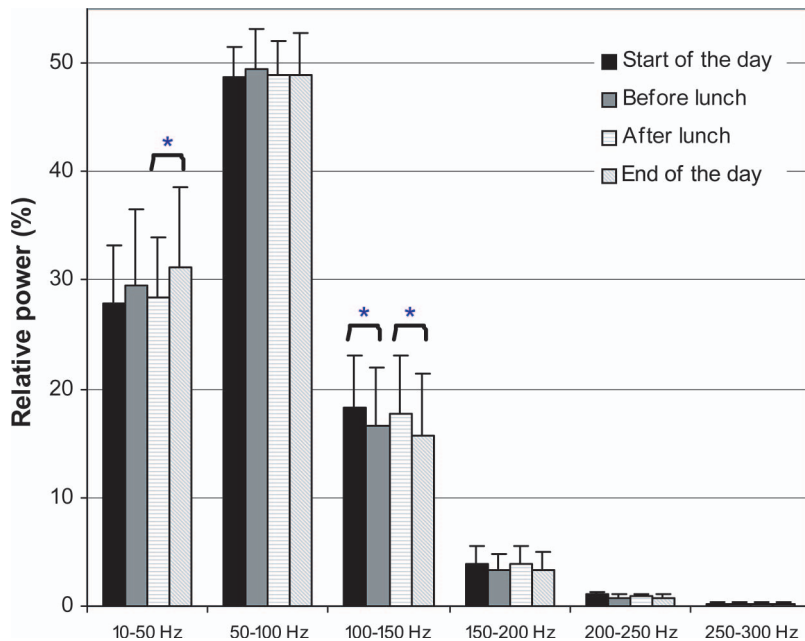
Figure 8. Relative power of each frequency band in relation to the total power on the second day of case study 2. The low frequency band (10–50 Hz) significantly increased after the lunch accompanied by a significant decrease in higher frequencies (150–200 Hz), indicated by *. Bars represent SD.

3.4. Discomfort

Figure 9a,b shows the development of discomfort in the neck and shoulder region for both case studies. The variation in neck and shoulder discomfort across subjects was large.

   In case study 1, a main effect of time on discomfort in the neck and shoulder region was found ($p = 0.007$). Post-hoc tests revealed significant increases during the first ($p = 0.016$) and second ($p = 0.05$) periods of the day. The decrease in discomfort during the lunch period, which may have indicated recovery, was not significant ($p = 0.153$).

   Discomfort was significantly higher on a 9.5-h working day in comparison to an 8-h working day ($p = 0.019$). However, no significant increase in discomfort was found in the extended work period (the final 1.5 h).

   In case study 2, a significant temporal change of discomfort in the neck and shoulder region was found ($p = 0.017$). Post-hoc tests showed significant increases during the first ($p = 0.023$) and second ($p = 0.012$) periods of the day. Discomfort did not decrease during the 30 min lunch break. Discomfort on the first and last working days of the week did not differ significantly.

3.5. Correlations between variables

Pearson's correlation coefficients were determined for the difference between the start and the end of the day (table 2) and the differences between the start and end of the working

(a)

(b)
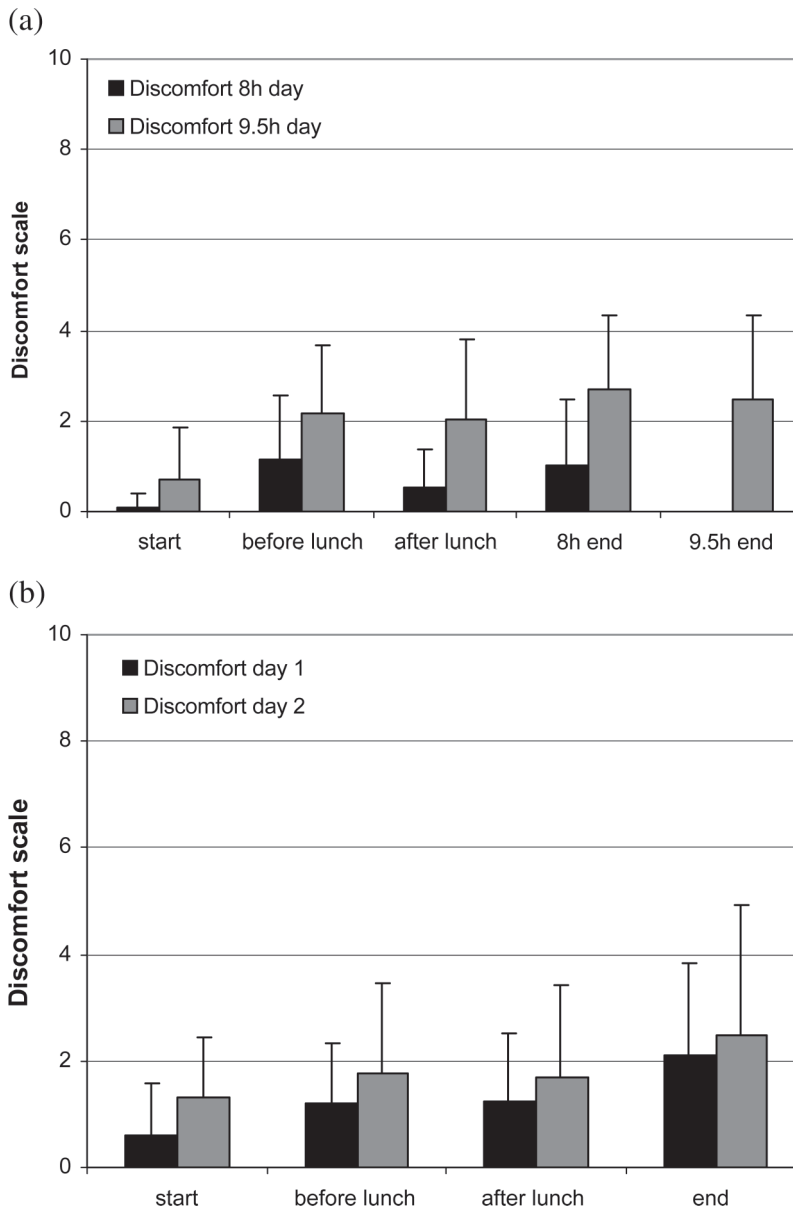
Figure 9. (a) Case study 1: discomfort in the neck and shoulder region for the extended and normal working days; (b) Case study 2: discomfort in the neck and shoulder region for the extended and normal working days. The discomfort rating scale ranged from 0 to 10 (almost maximum). Bars represent SD.

periods before and after lunch for EMG amplitude, MPF and discomfort rating (table 3). No relationship was found between subjective and objective estimates of muscle fatigue. Correlation coefficients were low and not significant.

Table 2. Correlation coefficients between objective and subjective estimates of fatigue.

	Case study 1 r (*p*-value)	Case study 2 r (*p*-value)
EMG amplitude – discomfort rating	0.13 (0.176)	−0.011 (0.975)
EMG MPF – discomfort rating	−0.59 (0.074)	−0.45 (0.192)

EMG = electromyography; MPF = mean power frequency.

Table 3. Correlation coefficients between objective and subjective estimates of fatigue during different work periods.

	Case study 1		Case study 2	
	Before lunch r (*p*-value)	After lunch r (*p*-value)	Before lunch r (*p*-value)	After lunch r (*p*-value)
EMG amplitude – discomfort rating	0.17 (0.963)	−0.51 (0.137)	−0.38 (0.282)	0.072 (0.843)
EMG MPF – discomfort rating	−0.39 (0.264)	0.38 (0.279)	0.38 (0.274)	−0.63 (0.051)

EMG = electromyography; MPF = mean power frequency.

4. Discussion

In the current study, the development of muscle fatigue over the course of a working day was investigated in two production companies together with the relationship between subjective and objective estimates of fatigue. This type of field research has some limitations in comparison with controlled laboratory experiments. The time period as well as the number of subjects is often restricted. In addition, there are many confounding factors related to production planning, capacity utilization, variation in products, (technical) disturbances and absence of subjects. These confounders are hard to control and have large effects. Conversely, field research has the obvious advantage that it requires no extrapolation of results to practice.

The EMG signals obtained in this field study showed indications of the development of muscle fatigue over the course of a working day. Indications of muscle fatigue include an increase of the EMG amplitude and a decrease of the MPF (Basmajian and DeLuca 1985).

In case study 1, EMG amplitude increased during the first part of the day while the MPF did not change significantly over time. In case study 2, an increase in amplitude of the EMG signal was accompanied by a decrease of the MPF during the first part of the day. A more detailed analysis of the frequency content (Dolan *et al.* 1995) showed an increase of the lower frequency band (10–50 Hz) accompanied by a decrease of the 100–150 Hz band in the first period of the second working day. As stated before, muscle fatigue might be an initiating factor of muscle disorders but the relationship between muscle fatigue and disorders was not investigated in this study.

Case study 2 demonstrated stronger indications of the development of muscle fatigue than case study 1. This may have been due to a higher work intensity in case study 2. The subjects' work pace in case study 1 was not driven by a production line. Subjects were free to move and had more opportunities to take short breaks, in contrast to the subjects in the second case study, who had a strictly determined work pace. In addition to the higher work pace, subjects in the second case study had to lift their arms higher and with a higher frequency.

Furthermore, the subject groups clearly differed between the two case studies. In the first case study, a mixed gender population was involved (six females and four males), while in the second case study only females were involved. Gender might be a bias and therefore no systematic comparison was made between the two cases.

No differences were found between the different working days. The extended working days did not show more signs of fatigue than the normal (8-h) working days (case study 1) and the last day of the week did not differ from the first day (case study 2). Only relative changes in EMG variables during the day were compared. Absolute MPF and amplitude values could be higher on the second day, but it was not possible to compare absolute differences as the electrodes were replaced in between days. Electrode location was visually controlled carefully, but small changes in electrode position may have occurred and skin resistance was not controlled.

The EMG signals in this study were obtained during test contractions. Under dynamic conditions, factors that hardly can be controlled (such as muscle length, muscle-electrode distance and movement velocity) may lead to erroneous interpretation of the EMG signals (Madeleine *et al.* 2001). Previous studies obtained positive results (Suurküla and Hägg 1987, Mathiassen and Winkel 1996) with a test contraction method. The test contraction used allows the recording of stationary signals that are likely to be produced by the same pool of motor units in every measurement. On the other hand, it is not known whether a contraction is representative of the workload and thus of the motor unit recruitment during the real task (Søgaard *et al.* 2003, Blangsted *et al.* 2005). An additional disadvantage is the disruption of the work process.

In addition to the indications of the development of objective muscle fatigue, local perceived discomfort in the neck and shoulder region was also found to increase in both case studies. Remarkably, there was no clear relationship between subjective indicators (perceived discomfort in the neck and shoulder region) and the objective indicators (MPF and amplitude of the EMG signal) of muscle fatigue. Sundelin and Hagberg (1992) were able to find a significant relationship between subjective (discomfort) and objective indicators (MPF and amplitude of the EMG of the trapezius muscle). However, that study used a 1-h strictly controlled laboratory task with a relative high intensity and measurement frequency (12 times/hour). No such relationship has been established so far, to the present authors' knowledge, in field research over the course of a working day.

The absence of a relationship might be explained by several factors. First, the ratings of local perceived discomfort obtained in occupational settings might be the result of other issues rather than discomfort. For instance, the subjective interpretation of an intervention (e.g. longer working hours) might influence the subjects' feelings of discomfort.

Moreover, discomfort also encompasses sensations of other sensory experiences such as pain and pressure as well as discomfort in tissues other than the muscles. Conversely, EMG measurements reflect only a small part of the physiological state of the muscle. Changes in the MPF and amplitude of the EMG signal are less consistent during prolonged low-level dynamic contractions than during high-force contractions (Nussbaum 2001, Søgaard *et al.* 2003). Physiological processes not reflected in the EMG signal (e.g. local blood flow, local metabolic changes, changes in the mechanical properties of the excitation contraction coupling) may play an important role in the development of fatigue during low-intensity work.

This study showed signs of fatigue but differences between conditions (normal vs. extended days, first vs. last day of the week) were not found. To be able to detect such differences, complementary objective methods may be needed. Possibly the use of

multiple surface electrode pairs on the muscle will increase sensitivity of EMG bases (Staudenmann *et al.* 2005). Activity of the trapezius muscle in this study was measured using one bipolar surface electrode pair. This is adequate if the muscle is homogeneously activated. However, this may not be the case during assembly work. Different muscle compartments may be activated independently during the performance of different elements of the tasks (Jensen and Westgaard 1995, 1997, Kleine *et al.* 1999). Therefore, the sensitivity of the estimations of upper trapezius muscle fatigue could be increased by using multi-electrodes.

Blangsted *et al.* (2005) used mechanomyography (MMG) to detect fatigue during short, low-intensity static contractions. Physiological features such as motor unit recruitment and synchronization of motor units are thought to be reflected by MMG measurements (Orizio *et al.* 2003) and could provide additional information on fatigue processes. Rosendal *et al.* (2004) used microdialysis to investigate intramuscular metabolism of the trapezius muscle during a 20 min repetitive low-force contraction exercise. An increase in pain was accompanied by a rise in local anaerobic metabolism. However, the use of this method in field studies is likely to be limited.

An increase in discriminatory power may be required here and these methods could help to achieve just that. This might further help in the definition and justification of temporal interventions such as changing the length of the working day, introducing extra pauses or task variation across time.

In conclusion, the development of muscle fatigue was indicated by both objective and subjective measurements. However, no clear relationship between the subjective and objective indicators of muscle fatigue was found.

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