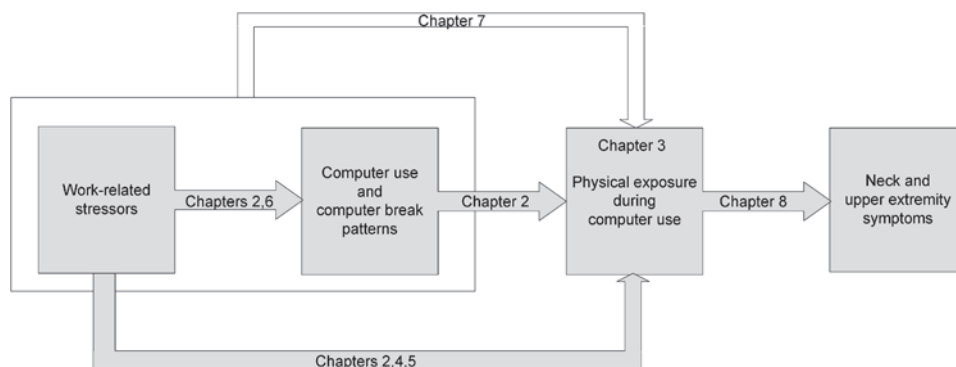


# CHAPTER 9

General Discussion

In this chapter, the main findings of the present thesis are discussed. The aim of the thesis was to provide insight into the mechanisms that relate work-related stressors to neck and upper extremity symptoms among office workers. We hypothesized that work-related stressors increase workers' physical exposures, partly through changed computer use and computer break patterns in response to these stressors, that in course of time can result in neck and upper extremity symptoms (Figure 1). We tested this assumption by examining the association between workers' levels of work-related stressors and directly measured neck-shoulder and arm-wrist-hand exposures in the field, and by testing whether high predicted neck-shoulder and arm-wrist-hand exposures during computer use put a worker at higher risk for developing neck and upper extremity symptoms.



**Figure 1.** Hypothesized pathways by which work-related stressors (directly or via computer use and computer break patterns) may affect computer workers' physical exposures and consequently the occurrence of neck and upper extremity symptoms.

The main aims of the present thesis were to:

- 1) Assess office workers' physical exposures during computer use in a realistic work setting (Chapter 3).
- 2) Examine the effects of a variety of work-related stressors on office workers' physical exposures in the neck and upper extremities during computer work, and whether these exposures were (partly) affected via altered computer use patterns (Chapters 2, 4, 5, and 6).
- 3) Examine methods to predict physical exposures among office workers in the field, to facilitate less expensive and less time-consuming data collection (Chapter 7).
- 4) Examine the effects of high levels of predicted neck-shoulder and arm-wrist-hand exposures during computer use in relation to work-related neck and upper extremity symptoms in a large cohort of office workers (Chapter 8).

In this chapter, the results that we observed will be placed in a wider context of the literature preceded by an evaluation of the study methodology that was used. Conclusions, suggestions for future research and practical implications will be addressed in the last part of this chapter.

## Main findings

*1) This thesis provided practical measurement techniques to assess office workers' physical exposures during computer use in a realistic work setting and demonstrated that exposures were different for keyboard, mouse, and idle activities.*

We assessed i) neck-shoulder and forearm muscle activity, ii) head, neck, torso, shoulder, and wrist postures and motions, and iii) forces applied to the keyboard and computer mouse in 120 office workers while they performed their normal computer work at their own workstations (Chapter 3). We used wireless and unobtrusive measurement devices, such as small wireless data loggers, that could be strapped around the workers' arms. In this way, the office workers were able to move freely like they would normally do, while we measured their physical exposures. For shoulder rotation measurements we used a custom video-based method, since 3D motion capture cameras that are frequently used in motion registration were not practical in this setting. This shoulder rotation assessment method has been shown to be valid (1).

The collected physical exposures were synchronized with each other and with computer usage data. Our data showed that workers' physical exposures in a field setting differed per computer task (keyboard, mouse, and idle activities), as had previously been observed in a laboratory setting (2).

*2) This thesis demonstrated that a variety of work-related stressors simulated in a laboratory setting increase muscle activity in the neck-shoulder and arm-wrist-hand regions. It also provided support for the hypothesis that work-related stressors increase physical exposures during computer use (directly as well as via altered computer use patterns) in office workers, based on direct measurements of physical exposure in the field.*

In a review of the literature, we found that various induced work-related stressors (cognitive/emotional stressors, work pace and precision) simulated in laboratory settings caused an increase of neck-shoulder and forearm muscle activity (Chapter 2). This increase was most likely a result of general arousal, since we found no indications that task-interfering stressors affected muscle activity in the postural muscles of the neck and shoulders differently than muscle activity in the muscles of the forearm, which are directly involved in task performance.

Furthermore, we found that high levels of overcommitment, a stressor that indicates to what extent extreme occupational commitment negatively impacts a worker personally, in combination with low levels of reward was associated with increased trapezius muscle activity and increased neck flexion (Chapter 4). Moreover, workers with high compared to low levels of overcommitment showed higher wrist velocities and accelerations (radial-ulnar deviation) and increased torso flexion (Chapters 4 and 5). Also, the work-related stressors overcommitment, reward, effort, and perceived stress, adversely affected workers' computer use and computer break patterns (Chapter 6). This means that workers with high compared to low overcommitment and workers with high compared to low perceived stress extended the total duration of computer use across a workday with approximately

30 minutes, while the duration of the workday itself was not extended. Workers with high compared to low effort and workers with low compared to high reward had fewer short computer breaks across a workday. Contrary to what we expected, the pace of keyboard and mouse usage was only weakly related to the work-related stressors, with only an association between effort and key strike duration, indicating that workers with high effort had a shorter key strike duration.

*3) This thesis yielded the use of prediction models as an alternative physical exposure assessment method for office workers in the field, because it allows less expensive and less time-consuming data collection.*

We predicted arm-wrist-hand exposures during computer use based on self-reported factors, software-recorded computer usage patterns, and additional worksite measurements of anthropometrics and workstation set-up (Chapter 7). The predictive quality of these models, evaluated using  $R^2$  values, was found to be quite variable among the different exposures, ranging between 0.19 and 0.80. We observed that keyboard and mouse forces could be predicted best, followed by median wrist muscle activity and wrist accelerations. Wrist postures were least accurately predicted.

*4) This thesis added some evidence for the association between neck-shoulder and arm-wrist-hand exposures during computer use and the risk of developing work-related neck and upper extremity symptoms among office workers.*

When testing the effects of high neck-shoulder and arm-wrist-hand exposures on neck and upper extremity symptom occurrence, our data revealed that high right trapezius muscle activity, large torso abduction, and high right wrist velocities (flexion-extension and radial-ulnar deviation) increased the risk of developing symptoms (Chapter 8). Large shoulder flexion was shown to be protective.

### **Methodological considerations**

The present thesis examined physical exposures in office workers with different levels of work-related stressors in relation to work-related neck and upper extremity symptoms. To this end, we performed detailed measurements of individual and work-related characteristics, computer usage patterns, and neck-shoulder and arm-wrist-hand exposures during computer work, such as muscle activities, postures, wrist velocities and accelerations, and forces applied to the keyboard and computer mouse, in 120 office workers (the PROOF study). Using prediction models, we combined these data with data of the PROMO study, a longitudinal study among almost 2000 office workers. While partial support for our hypotheses was found, it might be possible that we also have missed support that work-related stressors can increase the risk of developing neck and upper extremity symptoms via increased physical exposures, as a result of some methodological shortcomings. In the following paragraphs these methodological considerations are discussed.

First, examining differences between levels of work-related stressors in relation to physical exposures might have been hindered by misclassification in low, medium, and high work-related stress. To capture workers' current level of work-related stressors, we used questionnaires that either explicitly referred to the past or did not specify a time frame. We related these answers to workers' current physical exposures. To my knowledge there is no information in the literature clarifying to what extent these questionnaires indicate a worker's current stress level, and it is therefore unclear whether relating these with current physical exposures is appropriate.

Second, our results concerning the aforementioned relation could also have been influenced by low statistical power as a result of high intra-individual exposure variability in the physical exposure data. In turn, this could have hampered testing our overall hypothesis that high work-related stressors increased workers' physical exposures during computer use and that high physical exposures increase the risk for neck and upper extremity symptoms. High intra-individual variability, which can be defined as "the change in exposure over time" (3), has been indicated for surface electromyography, with changes over hours and days (4), as well as for postures (5;6). Regarding muscle activity measurements, we complied to recommendations for sufficient statistical power, being a measurement duration of at least one hour for single measurements and enrolment of at least 20 participants in each of two independent groups (to detect an exposure difference of 20%) (4;7). However, we did not comply to the advice to perform multiple measurements per subject, distributed across a workday and across different workdays (5-8), and we performed single-time exposure measurements only. As a result, relations may have gone undetected, or the strength of relations may actually be stronger than demonstrated in the present thesis. Another issue that has limited the extent to which we could test our overall hypothesis, is that we only examined physical exposures of workers while they were interacting with the computer. In the PROOF study we did not gather information about workers' physical exposures during other activities at work, and we were therefore unable to examine if these exposures were associated with neck and upper extremity symptoms. Since we found support for the pathway that work-related stressors can directly increase workers' physical exposures and not only via computer task interference (Chapter 2), it is reasonable to suggest that physical exposures during other activities, not including computer interactions, will also be influenced by work-related stressors. This suggestion is in line with reports in the literature, proposing that exposures during non-computer activities might also be of importance in the association with neck and upper extremity symptoms (9;10).

Third, regarding the relation between physical exposures and neck and upper extremity symptoms, we were only able to test 12 of the 30 physical exposure parameters that we had suggested to be relevant in relation to symptoms, because 18 of these exposures could not be predicted well enough. Predictions for these 18 physical exposures might be improved by including predictors of directly measured anthropometry, workstation set-up factors, and computer usage, as was shown in Chapter 7 (see also (11)). However, these data were not available in the PROMO dataset that we used to test the relation between the predicted physical exposures and neck and upper extremity symptoms. It could be that

the 18 physical exposures that remained unexamined in the present thesis in relation to neck and upper extremity symptoms, do show a relation with symptoms if they are better predicted. Similarly, the predictions of the 12 physical exposures that we were able to examine could be improved by including predictors of directly measured anthropometry, workstation set-up factors, and computer usage. In that case stronger relations with neck and upper extremity symptoms might be found or new statistically significant effects might be shown. Another consideration regarding this relation is that we only focused on median physical exposure intensities, whereas physical exposure variability, such as variability in muscle activity and postures, is also indicated as an important factor in the association with symptoms (12;13). It has been proposed that exposure variability is beneficial for neck and upper extremity health (13;14). Also, in people with symptoms, variability was found to be reduced (15;16). The fact that we only examined median physical exposure intensities might have underestimated relevance of some physical exposures in relation to neck and upper extremity symptoms, because for these exposures mainly exposure variability is of importance. A last aspect that could have influenced our findings concerning the relation between physical exposures and neck and upper extremity symptoms, is the duration of exposure. It is possible that especially the interaction of long computer use duration and high exposure intensity during computer use is important in relation to symptoms. So far, inconsistent results regarding the role of computer use duration in relation to symptoms have been reported. Effects of computer duration on prolonged symptoms have only been found for self-reported, but not for directly measured, computer use duration (17;18). In the present thesis, we were unable to examine the interaction effects of computer use duration and physical exposure intensity because we did not have sufficient directly measured computer use data in the PROMO cohort. How this interaction could have influenced the results in the present thesis may best be shown with an example. In Chapter 3, we found that trapezius and ECR muscle activity were highest during keyboarding. However, the 120 workers we observed, in general, only spent 21% of their total computer interaction time keyboarding. Taken together, the combination of high trapezius and ECR muscle activity and short duration of keyboard use might efface any increased risk. At the same time, the standard deviation of the amount of keyboard time as a percentage of total computer interaction time was quite large (11%), indicating large differences between workers. Especially workers with a large percentage of keyboard time might be the workers at an increased risk to develop symptoms, if also their muscle activity is high during keyboarding. Testing the interaction effects of computer use duration and physical exposure intensity in the present thesis, could have revealed larger differences in the risk to develop neck and upper extremity symptoms, and could have provided indications regarding safe computer use duration levels, on which we currently have no information.

## Interpretation of results

In the present thesis we have examined several associations as part of the hypothesized pathway relating work-related stressors to neck and upper extremity symptoms through increased physical exposures (Figure 1). In this paragraph the results of these individual associations, presented in the different chapters of this thesis, are combined. Our hypothesis was supported for overcommitment. For other work-related stressors, i.e. effort, reward, and perceived stress, our hypothesis was not or only partly supported. For example, we expected to find high forearm muscle activity and more adverse median wrist postures in workers with high levels of stress, but these assumptions were not supported by our data. We did, however, find a trend that predicted high forearm muscle activity increased the risk of arm-wrist-hand symptoms. Furthermore, results of forces applied to the keyboard and mouse were in contrast with our expectations. We expected to find high forces for workers with high levels of work-related stressors, but our data revealed slightly lower forces with high stress levels, which were close to statistical significance. We were not able to examine the relation between predicted high keyboard and mouse force and arm-wrist-hand symptoms, since we were unable to sufficiently predict forces when using only predictors that were also available in the PROMO dataset.

High overcommitment was shown to be associated with increased muscle activity of the trapezius (Chapter 4). In turn, high trapezius activity was found to increase the risk of neck-shoulder symptoms within the coming year (Chapter 8). Combining these results we might conclude that overcommitment increased the risk of neck-shoulder symptoms via an increased trapezius activity. However, the association between trapezius muscle activity and neck-shoulder symptoms was examined using predicted, instead of actually measured, trapezius muscle activity. Predicted trapezius muscle activity was based on 8 (for right trapezius) and 10 (for left trapezius) self-reported individual and work-related factors. These predictors were selected from 76 factors in total, including overcommitment. Overcommitment, however, was not included as a predictor of trapezius muscle activity in the two final prediction models for right and left trapezius muscle activity, since it was excluded in the last selection step. In this last step we used a more strict significance level (i.e.  $p < 0.10$ ) than in the former two selection steps (i.e.  $p < 0.20$ ), and the significance level of overcommitment was slightly above this cut-off value. This indicates that overcommitment and trapezius muscle activity were associated, but in the presence of other predictors, this association was not strong enough.

Furthermore, we found that workers with high compared to low overcommitment showed higher radial-ulnar wrist velocities and accelerations (Chapter 5). In turn, high radial-ulnar wrist velocities put workers at higher risk to develop arm-wrist-hand symptoms (Chapter 8). This association was examined using predicted wrist velocities. Again, comparable to predicted trapezius muscle activity, the radial-ulnar wrist velocity final prediction model did not include overcommitment. Strikingly, the final radial-ulnar wrist velocity prediction model did include the predictor: *“Does it often happen that you work over an hour at the computer without having a computer break of at least 5 minutes, such as reading a paper*

*document, using your telephone, having a discussion with a colleague, or having a coffee break?*, increasing velocity if answered with “yes”. This predictor is in line with our finding that workers with high compared to low overcommitment spent approximately 30 minutes more at the computer per workday.

The above findings suggest that overcommitment puts a worker at higher risk of work-related neck and upper extremity symptoms, possibly via increased physical exposures. However, there were also findings, contradicting our expectation, suggesting a preventive effect of overcommitment. High overcommitment resulted in higher trapezius muscle activity variability (which was defined as P90-P10) and higher shoulder abduction variability. It is suggested that high exposure variability is beneficial in relation to symptoms (15;16), but we have not examined this association with neck-shoulder symptoms. It is also possible that our finding of increased variability, in the way we defined variability, is a result of higher peak exposure (i.e. P90), which might actually increase health risks.

### *Suggestions for practice*

The goal of this thesis was to contribute to prevention of work-related neck and upper extremity symptoms among office workers. Through providing knowledge about the injury mechanisms, we aimed to identify factors that can be intervened upon. A schematic representation of possible injury pathways of neck and upper extremity symptoms originating from work-related stressors is depicted in Figure 1.

From an ethical point of view, a work environment has to be safe for all workers. From this perspective, efforts to prevent neck and upper extremity symptoms should aim at reducing the level of work-related stressors a worker has to deal with in his work environment. However, interventions focused on organizations are less common compared to interventions focused on individuals. For example, a Cochrane review on preventing work-related stressors in health care workers included 20 studies, of which fourteen examined interventions focused on the individual and only six studies examined interventions focused on the organization (19). Karanika-Murray and Weyman (20) suggested that one of the reasons that most intervention programs adopt an individual focus, can be attributed to typical perspectives of employers with respect to work-related stressors, which focuses on the consequences of ill health and sickness absence and thereby on individual workers. Another reason might be that interventions focused on the organization are more difficult to implement than interventions targeting individual workers.

Presumably, partly as a result of the underrepresentation of stress reduction intervention programs focused on organizations, there is a lack of studies evaluating the effects of such interventions and the results of the few that exist vary (21). However, promising results of interventions that focus on the organization to reduce stress and other, closely related, outcomes, such as workers health outcomes (i.e. general complaints, emotional exhaustion, and also musculoskeletal symptoms) and business outcomes (i.e. sickness absence, staff turnover, and work performance), underline the potential importance of these interventions (22-24). Although the potential of interventions focused on organizations was indicated in some studies others failed to show substantial effects, also challenging



researchers to identify factors that could explain these differences in study outcomes (25). Contrasting results might be explained by the large heterogeneity of the studies in sample sizes, time lags, intervention components, effect measures, and study context (cf. 26;27). For example, many studies evaluated only short-term effects, ranging between 3 and 12 months. However, it has been suggested that changes in organizations take a lot of time (28), and possible changes might therefore not be detectable within the time period between baseline and short-term follow-up measurements (cf. 29). Furthermore, contrasting results could be attributed to the fact that interventions focused on the organization target altering complex (dynamic) processes, in which many individuals are involved. These interventions include several components, complicating implementation and evaluation of the intervention (30). A recently published longitudinal study presents suggestions for proper implementation of interventions focused on organizations (31). For example, it showed that only participating in such interventions is not sufficient to achieve a desired effect, but that the intervention effect depended on whether workers attributed a high or medium/low impact to the programme. In summary, results of interventions focused on organizations are scarce but promising. However, we should not ignore the positive results of interventions that focus on the individual. It has been suggested that interventions targeting both the organization and the individual represent the best way forward to achieve sustained effects (32).

Stress reduction interventions that focus on the individual could aim to reduce the personal negative impact of work-related stressors, by providing workers skills to maintain healthy physical exposure levels during a workday. Following the hypothesis of the present thesis (Figure 1), this could be accomplished directly or indirectly via altered computer use and computer break patterns. Based on the results of the present thesis, the most obvious suggestion to contribute to future neck-shoulder symptom prevention programmes, is maintaining a safe trapezius muscle activity level. We indicated that trapezius muscle activity can increase as a consequence of work-related stressors. In turn, increased trapezius muscle activity puts a worker at higher risk to develop neck-shoulder symptoms. An intervention strategy that addresses workers' personal response to work-related stressors is myofeedback (also sometimes termed as EMG-biofeedback). Ma and colleagues (33) showed that muscle activity of the upper trapezius during office work (as well as self-reported pain) decreased, as a result of myofeedback training in subjects with neck and upper extremity symptoms. Similar studies on this topic reported comparable findings (i.e. reduced trapezius muscle activity and reduced pain experience) (34-38). Furthermore, the spatial variability of trapezius muscle activity during computer use can be enlarged using myofeedback techniques (39). A large variability has been suggested as possible preventive factor in the association with neck and upper extremity symptoms (15;16). Regarding temporal variability, Holtermann and colleagues (40) found an increase in the number of micro pauses within the trapezius muscle after myofeedback training, while working at the computer. This suggestion is in line with findings of Vollenbroek-Hutten and colleagues (38), who suggested that the long-term effect of reduced pain experience after myofeedback training, among computer workers with work-related neck-shoulder pain, possibly results from an improved ability to relax.

### Recommendations for future research

Although we found indications that work-related stressors can lead to neck and upper extremity symptoms via increased physical exposures, no firm conclusions can be drawn. We were not able to test the association between physical exposures and symptoms for all possibly relevant physical exposures as a result of some poor exposure predictions. Future research should therefore aim at further examining work-related neck and upper extremity symptom injury mechanisms, by including other possibly relevant physical exposures, such as shoulder, neck, and wrist postures. To obtain sufficient statistical power, I would recommend having multiple physical exposure assessments per worker, since intra-individual variability in these data is large. Furthermore, I would recommend having a longitudinal study design, which enables examining within-worker changes over time. Using a longitudinal study design, the association between within-subject changes of work-related stressors and within-subject changes of physical exposures can be examined. A longitudinal study design could also provide information about the stability of work-related stressors (overcommitment, reward, effort, and perceived stress) over time. In addition, with a longitudinal design the temporal relation between stressors and physical exposures can be studied, which seems of special interest for trapezius muscle activity as compared to other muscles (41). More specifically, it was shown that following a cognitive stressor muscle activity increased in six different muscles in the neck-shoulder region, but when this cognitive stressor was presented a second time, muscle activity in all muscles returned to a lower level except for the (upper) trapezius.

Prediction models provide an efficient and inexpensive way to produce large amounts of data and could facilitate the collection of large, longitudinal data sets to examine the relation between physical exposures and neck and upper extremity symptoms. The potential usefulness of physical exposure prediction models, based on self-reported individual and work-related factors, has been indicated in this thesis. However, the models we developed could not satisfactorily predict all possible relevant physical exposures during computer use and can therefore be improved in future studies, for example by including data regarding software-recorded computer usage patterns and worksite measurements of anthropometrics and workstation set-up. Furthermore, to improve generalizability of these models for usability in other data sets, they need to be externally validated.

To further examine the relation between physical exposures and neck and upper extremity symptoms, future studies should not only focus on physical exposure intensity. Investigating the interaction effect of duration and physical exposure intensities on neck and upper extremity symptom development could help determining general directives for safe computer use patterns. A recently published report that aimed to define such directives based on scientific information that is currently available, concluded that there was strong evidence for an increased risk to develop neck and upper extremity symptoms when computer work is performed for at least half a workday (42). However, the evidence, which was only based on self-reported computer use duration, was insufficiently consistent to formulate a cut-off value for healthy daily computer use duration to prevent neck and upper extremity symptoms among office workers.

Furthermore, following indications from the present thesis and from the literature that both physical exposure intensity and exposure variability are associated to the risk of developing symptoms, studies examining the interaction effect of exposure intensity and exposure variability could contribute to insight into the pathogenesis of neck and upper extremity symptoms. Future research should focus at examining this interaction effect in relation to symptom occurrence in order to demonstrate whether workers with a combination of high physical exposures and low exposure variability have a higher risk to develop symptoms, compared to the single effects of high exposure and low exposure variability.

A last recommendation for future studies is to also assess workers' physical exposures during other activities than computer work across a workday, which might also be relevant in relation to neck and upper extremity symptoms. Also interaction effects of these non-computer use physical exposure data and duration or exposure variability could be studied.

### **Final conclusions and practical implications**

The present thesis provided limited evidence for the hypothesis that work-related stressors can increase the risk of developing work-related neck and upper extremity symptoms through increased physical exposures. Both suggested pathways, directly and indirectly via altered computer use patterns (Chapter 6), might play a role in the injury mechanism. However, the findings from this thesis unfortunately did not shed light on the relative importance of these pathways. The direct influence of stressors on a computer worker's physical exposure is most likely a result of general arousal (Chapter 2). However, we were unable to distinguish which portion originates from computer task performance and which from general arousal, since we only assessed physical exposure data during computer use. As a result, we have no information on which of the two pathways is most important in relation to work-related neck and upper extremity symptom development, which could help improve future preventive interventions.

Our hypothesis was best supported for the work-related stressor "overcommitment". Overcommitment increased workers' physical exposures, which in turn increased the risk of developing neck-shoulder and arm-wrist-hand symptoms. For the stressors effort, reward, and perceived stress our hypotheses were not supported.

Assessing workers' physical exposures via prediction models based on self-reported data was found to be a useful assessment tool in this thesis, although we could only sufficiently predict 12 of the 30 neck and upper extremity exposures with the use of the available data in the present thesis. These exposure predictions can be improved by adding data regarding software-recorded computer usages patterns and worksite measurements of anthropometrics and workstation set-up.

Following the findings from the present thesis in the context of other research, my recommendations towards future work-related neck and upper extremity symptom prevention strategies are to mainly focus on reducing work-related stress levels in the work environment, but also on the personally experienced negative impact of these stressors. This can be accomplished by using a combined intervention approach targeting both the

organization and the individual. In addition, part of these future intervention programs could focus on maintaining a healthy trapezius muscle activity level during a workday, utilizing myofeedback training.

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