
SUMMARY

In **Chapter 1**, the main objectives of the present thesis were introduced. We started off by describing the possible role of work-related stressors in the aetiology of work-related neck and upper extremity symptoms, which is a common health problem among today's office workers. One of the most accepted theories is that work-related stressors increase workers' internal physical exposures during computer use, such as muscle activity, postures, velocities, and accelerations, which in turn may lead to tissue damage via overexertion. There are also indications that work-related stressors adversely affect workers' computer use patterns, such as reducing the frequency and duration of computer breaks across a workday, or working at a high work pace. So far, indications concerning possible injury mechanisms of work-related stressors are either based on effects of simulated work-related stressors in a laboratory setting, or on self-reported computer use patterns from the field. Since assessing workers' physical exposures during computer work in the field is challenging, field studies prospectively examining the relation between directly measured physical exposures and computer use patterns, on the one hand, and the occurrence of neck and upper extremity symptoms, on the other hand, are currently lacking. The use of physical exposure predictions, based on self-reported factors, expert observations, and/or software-recordings of computer use, could help facilitate testing this relation.

Addressing the role of work-related stressors in the aetiology of work-related neck and upper extremity symptoms in office workers, physical exposure assessment techniques for field studies, and future possibilities for alternative physical exposure assessment techniques, the present thesis had the following main objectives:

- 1) To assess office workers' physical exposures during computer use in a realistic work setting (Chapter 3).
- 2) To 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) To examine methods to predict physical exposures among office workers in the field, to allow less expensive and time consuming data collection (Chapter 7).
- 4) To 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).

The aims of **Chapter 2** were to review the effects of work-related stressors on neck-shoulder and forearm muscle activity, and to determine whether the muscles in the neck-shoulder and the forearm regions were affected differently by different types of work-related stressors (i.e. cognitive/emotional stressors, which do not necessarily interfere with task performance, for example cognitive load and performance feedback, and task interfering stressors, such as work pace and precision demands). In order to answer our research

questions, we performed a systematic literature search on studies investigating the relation between simulated or realistic workplace stressors and neck-shoulder and forearm muscle activity. Only studies that met the inclusion criteria were selected and included: muscle activity data had to be measured during computer mouse use, keyboard use or use of simulated keys as input device and participants had to be free of pain or other symptoms in the neck-shoulder and forearm regions. A risk of bias assessment was performed and data were extracted for synthesis. Muscle activity data were pooled when possible and otherwise described. The literature search generated a total of 6,484 references, of which 28 articles met our inclusion criteria and could be included in the study, reporting data of 25 different studies. Except for one field study, all included studies were laboratory studies. Data of 19 articles could be included in the meta-analysis, which revealed a statistically significant, medium increase in neck-shoulder and forearm muscle activity as a result of work-related stressors. To answer our second research question, we performed subgroup analyses, for cognitive/emotional stressors, work pace, and precision separately, indicating a similar effect of the different stressor types on muscle activity in the neck-shoulder and forearm regions. The literature review revealed a lack of field studies on this topic. This is important, since effects of simulated stressors in a laboratory setting might be different from effects of realistic stressors in an actual work setting.

In **Chapter 3**, we assessed office workers' physical exposures during computer use in a realistic work setting. Physical exposures included trapezius and extensor carpi radialis muscle activity, head, neck, shoulder, torso, and wrist postures, as well as forces applied to the computer mouse and keyboard. We examined whether there were differences in physical exposures across computer activities, including keyboard use, mouse use, and idle time. Idle time represented periods during which a worker is not using one of the input devices, but does interact with the computer, such as reading from the screen. Physical exposure parameters were measured continuously for 120 office workers, who performed their own work for two hours at their own workstations. There were differences in nearly all outcome measures (i.e. muscle activity, postures, and forces) across keyboard, mouse and idle activities. Keyboard activities showed a 50% increase in the median right trapezius muscle activity when compared to mouse activities. Median shoulder rotation changed from 25 degrees internal rotation during keyboard use to 15 degrees external rotation during mouse use. Only keyboard use was associated with median ulnar deviations greater than 5 degrees (a wrist posture that has been associated with an increased risk of symptoms). Idle activities led to the greatest variability observed in both muscle activity and postures.

To test the hypothesis that work-related stressors increase office workers' physical exposures during computer use, we examined in **Chapter 4** whether the work-related stressors overcommitment and reward, or their interaction, affected trapezius muscle activity and head, neck, shoulder, and torso postures during computer use. Our findings were based on direct measurements, over a 2-hour period, among 120 office workers performing their own work in their natural work environment. We measured physical

exposure data across four groups (lowest/highest reward/overcommitment). Median trapezius muscle activity and median neck flexion were largest for participants reporting simultaneously high overcommitment and low reward. No differences were observed for other muscle activities or head, neck, shoulder, and torso postures. These findings suggest that the interaction of reward and overcommitment can affect upper extremity muscle activity and postures during computer use in the real work environment.

Chapter 5 presented the effects of the work-related stressors high overcommitment, low reward, and their interaction on forearm physical exposures (i.e. forearm muscle activity, wrist posture and kinematics, and forces applied to computer input devices) during computer use in an actual field setting. We continuously measured wrist extensor muscle activity, wrist postures and kinematics, and forces applied to the keyboard and mouse for two hours during the daily work of 120 office workers with four different levels of overcommitment and reward (low-high, high-high, low-low, and high-low). We found that radial-ulnar wrist velocities and accelerations were higher for workers with high compared to low overcommitment, while their wrist range of motion was similar, which might indicate a higher work pace among highly overcommitted workers. Wrist extensor muscle activity and keyboard and mouse forces were not increased by high overcommitment, low reward, or their interaction.

To test our hypothesis that work-related stressors can increase office workers' physical exposures during computer use via altered computer work patterns, we reported in **Chapter 6** the effects of overcommitment, effort, reward, and perceived stress on workers' i) total computer use duration, ii) number of breaks from computer activities (i.e. ≥ 2 -30s, ≥ 30 s-5min, ≥ 5 min-15min, and ≥ 15 min), and iii) pace of input device usage (i.e. key strike frequency, key strike duration, mouse movement speed, and mouse clicking frequency) during a workday. We used data, collected using computer interaction monitoring software, of 93 office workers in whom keystrokes and mouse activities were measured for approximately two work weeks. Total duration of working at the computer per day was significantly longer, 30 minutes on average, for workers with high compared to low levels of overcommitment and perceived stress. The number of short computer breaks (i.e. ≥ 2 -30s and ≥ 30 s-5min) was significantly smaller by about 20% for those with high compared to low effort and for those with low compared to high reward. We did not find substantial effects of work-related stress on the pace of input device usage. Only after controlling for age, the duration of key strikes was shorter by 22 ms on average for those reporting high effort compared to those reporting low effort. In summary, perceived stress and overcommitment were associated with computer duration and effort and reward with low break frequency. These findings support the hypothesis that office workers' computer work patterns vary across individuals with different levels of work-related stress.

In **Chapter 7**, we explored the use of alternative physical exposure assessment techniques enhancing less expensive and time consuming data collection. This would

facilitate future large prospective cohort studies examining physical exposures in relation to work-related neck and upper extremity symptoms, which are currently lacking due to the challenges associated with measuring physical exposures in the field. In order to do so, we evaluated models that predict arm-wrist-hand physical exposures (i.e. muscle activity, wrist postures and kinematics, and keyboard and mouse forces) during computer use. These prediction models were based on self-reported factors (including individual factors, job characteristics, computer work behaviours, psychosocial factors, workstation set-up characteristics, health and pain characteristics, and leisure time activities) and software-recorded computer usage patterns alone (practical models), and with additional worksite measurements of anthropometrics and workstation set-up (models aimed at best achievable predictive quality). We evaluated the predictive quality of the practical models in terms of correlation error (R^2 values and relative root mean squared (RMS) errors) and classification agreement to low, medium, and high exposure categories. The models that aimed at best achievable predictive quality were only evaluated by determining R^2 values and relative RMS errors. The practical models had lower R^2 values (range: 0.09-0.40) and lower relative RMS errors (range: 10%-19%) compared to the models that aimed at best achievable predictive quality (range R^2 values: 0.19-0.80, range relative RMS errors: 5%-24%). When the predicted physical exposures of the practical models were classified into low, medium, and high, classification agreement ranged from 33% to 75% and was satisfactory for the most contrasting (low and high) groups. Prediction models that aimed at best achievable predictive quality, showed reasonable predictive quality. However, the results varied largely across different arm-wrist-hand exposure parameters.

In **Chapter 8**, we combined information from detailed measures of physical exposures in a small study population with survey measures in a large, longitudinal cohort to examine the relation between physical exposures during computer use and the onset of neck and upper extremity symptoms. We developed models to predict 14 different neck-shoulder and 16 different arm-wrist-hand exposures, using self-reported predictors and directly measured physical exposure data from 120 computer workers. We evaluated the predictive quality of all 30 models, by determining the classification agreement between the predicted and observed high, medium, and low exposures (based on tertiles) using cross tabulations. If in the reference category less than 50% of the predicted exposures were correctly classified, we defined that predicted exposure as insufficient. We were able to sufficiently predict five neck-shoulder and seven arm-wrist-hand exposures. These twelve prediction models were applied to 1,220 and 1,379 office workers from a large longitudinal cohort study, who were, at baseline, free from symptoms in the neck-shoulder and arm-wrist-hand region, respectively. Using logistic regression analyses we then tested the effects of high predicted exposures on the onset of neck and upper extremity symptoms at four different moments, using 3-month follow-up periods. We found that workers with high predicted trapezius muscle activity (right side), high values of predicted lateral torso tilt, and high predicted right wrist velocities during computer use were more at risk for developing symptoms. Workers with high predicted shoulder flexion were less at risk for developing symptoms

compared to those with low shoulder flexion. Our hypothesis that high physical exposures during computer use increase the risk for developing neck and upper extremity symptoms, was partly supported by these findings.

Chapter 9 discussed and interpreted the main findings with respect to the hypothesized pathways by which work-related stressors may affect computer workers' physical exposures and consequently the occurrence of neck and upper extremity symptoms. This chapter also addressed conclusions, suggestions for future research and practical implications. Regarding the main findings, we indicated that simulated stressors in a laboratory setting as well as work-related stressors in a realistic work setting can increase workers' physical exposures during computer work in both the neck-shoulder region and forearm region. Furthermore, we found that observed work-related stressors in the field can adversely alter computer use patterns among office workers. Also, high physical exposure levels during computer use were indicated to increase the risk of neck and upper extremity symptoms, using predicted exposures. Taken together, the results of the present thesis provided some support for our hypothesized injury pathway. Although we were only able to examine the single effects of high physical exposures in relation to neck and upper extremity symptoms, it is possible that interaction effects of high physical exposures and adverse computer use patterns, resulting from work-related stressors, have a greater effect on the onset of symptoms. This is one of the suggestions for future research that is described in this chapter. Interventions aiming to reduce the occurrence of symptoms among office workers could target on reducing the level of work-related stressors. Recent studies indicate that the best way to accomplish this is via interventions that focus on the work organization as well as on the individual. In addition, interventions could target on remaining safe physical exposure levels throughout a workday. As an example, the possibility of myofeedback to remain healthy trapezius muscle activity levels was discussed.