

### THESIS SUMMARY

Physical work load is considered an important risk factor for low-back pain (LBP). However, in **Chapter 1** it is also argued that reported associations between physical workload and LBP are rather inconsistent. This inconsistency is a barrier for the understanding of the etiology of LBP. One reason for this lack of knowledge may be inadequate quantifications of mechanical loads in work situations. It was argued that, in most models for LBP etiology, these mechanical loads (i.e., loads at the level of the lower back, for example, low-back moments as indicators for mechanical load, or compression or shear forces on the lumbar spine) are at the end of the causal chain, thereby providing a rather direct relationship with spinal damage. Different exposures (e.g., lifting, twisting and bending) affect the same mechanical load, so that mechanical load can be considered a ‘final common pathway’ to spine injury. Therefore, obtaining mechanical load metrics in prospective studies seems to be important when striving to obtain more understanding of the etiology of LBP. However, such studies are lacking, probably because of the absence of occupational assessment tools that are easily applicable in field situations. Furthermore, also other measurement issues that affect the outcome of such risk associations are insufficiently understood. Therefore, four aims were addressed in the current thesis. The main findings regarding these aims will be discussed in the following sub-paragraphs. Subsequently, general conclusions will be drawn based on this thesis, and future directions for research and ergonomic practice will be discussed.

#### *The predictive value for LBP of mechanical loads as compared to (subjective) exposure estimates*

As mechanical low-back loads have been assumed to be more predictive for LBP than exposures (i.e., obtained from self-reports or from observations), our initial goal was to test this hypothesis in a prospective cohort study. Data presented in **Chapter 2** show that although trained observers were able to predict neck and shoulder pain, they could not predict LBP well. This can be explained by the fact that compared to neck and shoulder load, low-back load depends on a larger number of task variables (i.e. trunk posture, arm posture, load magnitude and load distance) that seem to be difficult to assess subjectively. The finding that risk estimates of LBP are not significantly associated with LBP prevalence questions the accuracy of these subjective risk estimates and advocates for the use of precise measurements rather than estimates.

From the findings reported in **Chapter 3**, we can conclude that cumulative mechanical low-back load, as obtained from calculations of mechanical back load based on posture observation, is a significant predictor of LBP. Moreover, it was shown that this mechanical load metric has a stronger association with LBP than earlier reported exposure risk factors (i.e., time in a flexed position and number of lifts during a working day). These findings support our hypothesis that a mechanical low-back load measure provides a stronger

association with LBP than exposure measures. Based on these results it seems justified to develop more precise methods to assess mechanical loads at the workplace. Furthermore, mechanical load variables should be considered in future epidemiological studies to obtain more information on LBP etiology.

#### *The effects of methodological issues on the predictive value of low-back loads for LBP*

As a second step towards a better understanding of the LBP etiology we assessed the impact of some methodological issues that are of importance in epidemiological studies on the matter. In cumulative mechanical loads, the (peak) low-back load magnitude of a given work task is often multiplied by the number of load cycles of that particular task, while these multiplications of all tasks during a work shift are summed. However, it has been argued that high forces have more impact on the increase in failure risk than a high number of cycles. **Chapter 4** confirms this hypothesis by a re-analysis of in-vitro mechanical loading to failure data. This analysis showed that weighting compression forces and number of load cycles with exponents of 2 and 0.2, respectively, provides the best prediction of in vitro lumbar spine failure following cumulative loading. This non-linear load-failure association has implications for future studies assessing the effect of cumulative low-back loading for investigation of LBP etiology.

Another methodological issue that we have assessed is the effect of group size in group-based measurement protocols on the statistical power of eventual risk associations (**Chapter 5**). In group-based measurement protocols, workers are grouped according to common characteristics, such as their work tasks. Group-averaged exposure estimates are assigned to all workers in the group on the basis of data measured in a subgroup only, while outcome data (i.e., LBP) are assessed for all workers. Such protocols are often used in epidemiological studies on physical risk factors of LBP. Our results show that the power in such a group-based study depends more on the total number of workers included in the study (using individual outcome data on LBP) than on the size of the subpopulation from which exposures are obtained. Effectively, in order to reach a power of more than 0.80 at a p-level of <0.05, in general, at least 30 workers have to be included in each task group, with exposure measurements of at least 5 of these workers. When exposure was observed from fewer than 5 workers, the odds ratio (OR) of the exposure-outcome relationship was negatively biased. Therefore, findings suggest that although exposure of sufficient workers ( $\geq 5$ ) should be assessed in order to avoid bias of the OR, it seems to be more efficient to assess LBP from a larger number of workers ( $\geq 30$  per task group).

#### *The applicability of video based quantification of mechanical low-back load in a field situation*

Measuring mechanical low-back loads in field settings is a tempting task, as current measurement methods often interfere with the employer’s work or only crude metrics are

used. Therefore, a video analysis method for the assessment of mechanical low-back loads in the field was developed, based on earlier work. This analysis method can potentially be used in ergonomics practice and in future epidemiological studies as video material can be collected without interfering with the worker's tasks. **Chapter 6** describes a study in which this video analysis method for the assessment of low-back moments during occupational lifting was validated by performing a comparison with a laboratory reference method. No overall differences in peak and mean moments between the reference method and the video analysis methods were found and intra-class correlation coefficients (ICCs) revealed a strong correspondence of the video analysis method and the reference method. In **Chapter 7**, the inter-rater reliability of the video analysis method was tested on video material that had been recorded in field settings. Results from this chapter show excellent agreement among raters (ICC >0.9), while inter-rater variation was relatively low (<10 Nm), for low-back moment estimates of peak and mean moments. However, occasional substantial errors were shown during the assessment of manual material handling (MMH) tasks. These errors appeared to result from amplification of random posture rating errors in tasks of short duration, especially in MMH tasks that are difficult to rate because they were filmed from a non-sagittal view. Despite these errors, it can be concluded that the current video analysis method is valid as well as reliable. The latter is also the case when assessing occupational field tasks.

#### *The etiology of LBP using mechanical load metrics*

In the final study described in this thesis (**Chapter 8**), the video analysis method was applied to a large prospective cohort. Mechanical loads were assessed and their association with LBP was estimated. This study shows that cumulative mechanical low-back loads predict LBP. However, the required exponential weighting of force level appeared to be lower than predicted from the in-vitro data analyzed in Chapter 4. Nevertheless, these findings are in favor of the mechanism for the etiology of LBP described in Chapter 1, where cumulative loads play an important role in the cause of LBP, potentially as a result of accumulation of micro-damage, and/or through impaired coordination due to fatigue. As peak loads are not significantly associated with LBP, instantaneous tissue failure due to peak loads on the spine is a less probable cause of LBP based on the current data. However, the latter mechanism for etiology cannot be ruled out, especially as our data suggest that a weighting of load magnitude with a power larger than 1 in calculations of cumulative loads provided a better fit to our data.

#### GENERAL DISCUSSION

A number of general conclusions can be drawn from the current thesis. First of all, regarding the predictive value for LBP, a clear advantage was shown for the use of mechanical load metrics over exposures obtained by subjective assessments or structured posture observation. This is in line with data from a cross-sectional study (Norman et al., 1998) and with several models arguing that mechanical loads (i.e., loads at the level of the lower back, such as compression forces on the lumbar spine or low-back moments) are at the end of the causal chain and thus provide a more direct relationship with spinal failure and consequently with LBP (Chaffin, 2009; Marras, 2012). This direct relation stems from the fact that these mechanical loads can provide information on duration, frequency and intensity of multiple exposures. Quantification of exposures (i.e., number of lifts or time working in an awkward posture) is not directly related to the quantification of mechanical load variables. Furthermore, mechanical loads also take other mediating factors into account such as psychosocial factors, personal factors and work-related factors (as discussed in Chapter 1). Because of the arguments above, in the present thesis, mechanical loads were considered in order to obtain more information on LBP etiology. In this section the most important sources of error in quantifying low-back load with the methods used in this thesis, and their implications, will be discussed.

#### *The use of posture observations in biomechanical models*

Mechanical loads can be obtained by combining information from measured hand forces and structured posture observations in a biomechanical model, as often used in epidemiological studies. Such mechanical loads are predictive for LBP, as has been described in Chapter 3. However, this chapter describes only a first attempt to quantify low-back mechanical load in a prospective study. It has been shown before that using observational data as input for a biomechanical calculation, can lead to large inaccuracies (de Looze et al., 1994b). These inaccuracies can be illustrated by some simple examples based on data of the study described in Chapter 3. In these examples, a static procedure is used, estimating low-back moments from the moments caused by the gravitational force on the upper body with respect to the low-back and of the moments caused by the external force on the hands with respect to the low-back. Let us consider two causes of errors in back load estimates based on the observation of MMH tasks: inaccuracy due to crude categorization of the trunk flexion angle and misclassification of a MMH task. Consider a MMH task that is rated by an observer as being performed in a trunk flexion category ranging from 30 to 60°. When comparing two lifting tasks in which a 15 kg load is lifted with the arms downward and the trunk in the extremes within this category (30 or 60° flexion), moment arms of the upper body and the external force on the hands can differ considerably between these extremes. With 30° trunk flexion, the moment arms of the upper body and of the hands are about 20 cm and 30 cm, respectively. However, during 60°