Summary

Work is increasingly recognized as essential for maintaining health, even in the presence of health problems. With aging workforces and rising retirement ages, there is a growing need to support workers in maintaining sustainable employable (SE) over the course of their careers. SE is shaped by the interaction between individuals and their context, such as job requirements and the social environment. But its long-term nature makes accurate measurement and prediction challenging.

This study was conducted in the Netherlands, where SE has been operationalized in terms of workability, vitality and employability. In this study, we used workability and vitality, because these are assessed during regular Occupational Health Check-ups (OHCs) performed by the Occupational Health Supplier, the company where the data were collected.

In the Netherlands, OHCs are a widely used method for assessing and improving SE. Individual employees are assessed through multiple questionnaires on lifestyle, personal and health characteristics, and work-related factors combined with biometric health measurements. This is often carried out by occupational physiotherapists.

However, the effectiveness of OHCs in enhancing SE remains unclear. Several factors may contribute to this uncertainty. First, current PMOs often focus on disease symptoms or reduced employability rather than on protective factors for SE. Resilience reflects someone's ability to adapt to adversity, and screening for resilience may help identify early protective factors for SE. However, resilience remains understudied as a factor influencing SE. .Another possible reason is that an OHC is composed of multiple questionnaires. As a consequence, the OHC may be experienced as one long and complex questionnaire. It is unclear whether this affects the reliability of individual questionnaires. Additionally, the long PMO may be difficult for some people to complete, particularly those with language or reading difficulties.

Finally, the questionnaires used in OHCs have been validated separately rather than as part of an integrated system, leaving the predictive value of combined measures unknown. The interpretation of OHC results is complex and at times results are discrepant, which might lead to variations in advice, differences in effectiveness of interventions and potential inequality among workers.

Innovative approaches are needed to address these limitations. Machine Learning (ML) offers a promising solution by analyzing OHC data to identify complex patterns that traditional methods might miss. While ML-based decision support tools (ML-DSTs) have shown potential in other fields, they have not yet been validated for SE in occupational health settings. An ML-DST could use OHC

data to advise on which interventions work for individual workers to improve SE, enabling occupational physiotherapists to provide tailored, evidence-based advice.

The main aim of this PhD project was to increase the evidence base for advice provided by professionals in occupational health, such as occupational physiotherapists, regarding workers' SE. We aimed to apply innovative methods to improve decisions after an OHC, leading to more efficient, effective, and individualized advice. Two specific sub-aims included: 1) to evaluate the predictive value of measures of resilience as proxies for SE, and 2) to develop and evaluate a Machine Learning-Based Decision Support Tool for OHCs with the aim to increase SE. **Chapter 1** introduces the topic of the thesis and also presents the main objectives and the thesis outline.

The aim of the literature study **in chapter 2** was to identify factors contributing to SE. As previously described, demographic changes influence employability and health of the working population, with new challenges emerging. The focus has shifted from return to work only, to enhancing ability to stay at work. It is unclear whether factors that influence return to work (RTW) also apply to preserving health and helping workers stay at work. Objectives of this study were to identify factors contributing to SE among industrial workers and map identified factors to the Arena of Work Disability Prevention model (WDP-Arena, a commonly used RTW model) to identify agreements and differences. A scoping review was conducted, in which the process was not linear but iterative. This required the researchers to engage with each stage in a reflective way and, where necessary, repeat steps to ensure that the literature is covered comprehensively. Eight databases were searched between January 2005 and January 2020. Manuscripts with stay at work as an outcome were included, whereas those with early exit from work, such as (early) retirement or work disability, were excluded. Factors contributing to SE were mapped against the components of the Arena Model of Work Disability Prevention (WDP-Arena). The search resulted in 3,311 unique manuscripts and after all phases of screening, 13 manuscripts were included. Most factors that determine SE in industrial workers could be mapped onto the WDP-Arena. The WDP-Arena is structured around systems that influence workers' employability. The identified factors were most often related to the Workplace and Personal systems. Compared to RTW, in industrial workers many elements of the Legislative and Insurance systems and the Health Care system have not been studied for SE. This observation also applies to the societal/cultural/political context, which was not studied. New influencing factors were found that could not be mapped because they are multidimensional (workability, vitality at work, balanced workstyle, general health, dietary habits). The life-course perspective in SE is more evident than in RTW. This study enhanced the understanding of factors that contribute to SE.

One of the main aims of the thesis was to use ML to develop a decision-support tool to optimize advice following an OHC. Use of an ML-DST will likely change the interaction between occupational physiotherapists and workers, but the impact is not yet clear. In **chapter 3,** the ethical considerations and possible effects of using ML-DSTs in the occupational health context were explored to provide guidance during our ML-DST development. An ethical deliberation was conducted, supported by a narrative literature review of publications about ML and DSTs in the occupational health context. The potential impact of ML-DSTs was assessed according to frameworks from medical ethics and the philosophy of technology. A hypothetical scenario involving an OHC was used to reflect on the four ethical principles: respect for autonomy, beneficence, non-maleficence, and justice

Respect for autonomy may be affected because workers may not fully understand the long-term consequences of consenting to the use of their data, especially given the changing nature of ML-DSTs. Beneficence is influenced by how ML-DSTs impact the three pillars of evidence-based practice: scientific evidence, clinical expertise, and worker preferences. The principle of non-maleficence is challenged by the need to balance group-level benefits with potential harm to individuals, the vulnerability of workers in an occupational context, and the risk of using ML-DSTs for purposes beyond their original intent (function creep). Justice might improve when ML-DSTs function as intended, but profiling and discrimination remain potential risks.

This study emphasizes the importance of socially responsible development and implementation of ML-DSTs. To minimize negative effects, three specific recommendations were proposed: 1) the importance of 'educating' the ML-DST well by providing it with the best available data, training it with the best available algorithms, discussing its ethical impact and validating the ML-DST, while consulting all relevant stakeholders, 2) formal assessment by Health Research Ethics Committees, considering the occupational context, 3) education of professionals (e.g., occupational physiotherapists) in the strengths and weaknesses of ML-DSTs.

To measure resilience in an OHC, the Brief Resilience Scale (BRS), translated to Dutch, and Heart Rate Variability (HRV) were introduced. Before evaluating the predictive value of measures of SE, in **chapter 4** the measurement properties of the Dutch Language Version of the Brief Resilience Scale (BRS-DLV) in blue- and white-collar workers employed at multiple companies were studied and the validity and factor structure compared to other language versions. The BRS was translated to Dutch as part of this study. In a cross-sectional design, 1,023 workers were assessed during the OHC, including the BRS-DLV. Construct validity of the BRS-DLV was tested with exploratory and confirmatory factor analyses (EFA and CFA) and five hypotheses were tested: workers have significantly higher scores on the BRS-DLV when they (1) do not smoke, (2) spend more time in

recreational activity and (3) have a healthy diet. The BRS-DLV has significant correlations with: (4) psychological complaints and (5) with work engagement. Reliability was tested with Cronbach's alpha. A two-factor structure of the BRS-DLV had good model fit in both EFA and CFA, which could be explained by difficulties of workers with reversed order items. After excluding these inconsistent answering patterns, a one-factor structure showed good model fit resembling the original BRS. Internal consistency is sufficient (Cronbach α=0.78). All five hypotheses were confirmed, suggesting construct validity. It was concluded that reliability of the BRS-DLV is sufficient and there is evidence of construct validity. Inconsistent answering, however, caused problems in interpretation and factor structure of the BRS-DLV. This can be easily detected and handled because items 2, 4 and 6 are in reversed order. Other language versions differ in factor structure, most likely because systematic errors were not corrected for. To collect valid data, it is advised to be aware of inconsistent answering of respondents.

Additionally, the biometric measure of resilience (HRV) was explored for its association with other OHC measures in **chapter 5**, while predictive value was evaluated in **chapter 6.** Low HRV is related to health problems that are known reasons for sick-leave or early retirement. A 1-minute-protocol could allow large scale HRV measurement for screening of health problems and, potentially, sustained employability. In a cross-sectional design with 877 employees, HRV was assessed during an OHC. Personal and job characteristics, workability, psychological and mental problems, and lifestyle were measured with questionnaires. Biometry was measured (BMI, waist circumference, blood pressure, glucose, cholesterol). HRV was assessed with a 1-minute paced deep-breathing protocol and expressed as Mean Heart Rate Range (MHRR). A low MHRR indicates a higher health risk. Groups were classified into three groups, adjusted for age: normal to high MHRR, low MHRR, very low MHRR. The participant and work characteristics were compared between the groups. Spearman correlations between raw MHRR and the other items of the OHC were calculated. Significant univariable correlations (p<0.05) were entered in a linear regression model to explore the multivariable association with MHRR. Results showed that age, years of employment, BMI and waist circumference differed significantly between HRV groups. Significant correlations were found between MHRR and age, workability, measures of obesity (BMI, waist circumference), cholesterol, systolic and diastolic blood-pressure and self-reported physical activity and alcohol consumption. In the multivariable analyses 21.1% of variance was explained with low HRV correlating with aging, higher BMI and higher levels of reported physically activity.

The results from both chapter 4 and chapter 5 supported the continued evaluation of the BRS-DLV and HRV for assessing resilience and predicting future SE (**chapter 6**). Screening for resilience could

contribute to early detection of either risks or protective factors for SE, the latter being operationalized as workability and vitality. The objective was to study the predictive value of HRV measurements and the BRS-DLV for worker self-reported workability and vitality after 2– 4 years. A prospective observational cohort study with mean follow-up period of 38 months was conducted. 1,624 workers (18 - 65 years old) in moderate and large companies participated. Resilience was measured by HRV (one-minute paced deep breathing protocol) and the BRS-DLV at baseline. Workability Index (WAI), and the Vitality dimension of the Utrecht Work Engagement Scale-9 (UWES-9-vitality) were the outcome measures. Backward stepwise multiple regression analysis ($p<0.05$) was performed to evaluate the predictive value of resilience for workability and vitality, adjusted for body mass index, age and gender. A total of 428 workers were included after follow-up. The contribution of resilience, measured with the BRS-DLV, was modest but statistically significant for the prediction of vitality (R^2 = 7.3%) and workability (R^2 = 9.2%). HRV did not contribute to prediction of workability or vitality after 2-4 years. Age was the only significant covariate in the WAI model. Self-reported resilience may provide early insight into the ability of workers to stay at work, although caution must be applied because explained variance was modest.

In **chapter 7**, the development of the ML-DST is described. The tool is based on OHC data and aims to inform occupational physiotherapists when advising workers on lifestyle changes to enhance SE. The performance of the applied algorithms is subsequently evaluated. Data from real-world OHCs in the population-based cohort study (2010 - 2020) served as input for the ML-DST model development aimed at offering advice on lifestyle changes (physical activity, smoking, alcohol, nutrition, relaxation or no-change) to enhance workability and vitality. Paired baseline and (1-4 year) follow-up data were used to train and evaluate twelve models, each with three rule-based algorithms. The performance was considered as useful when both True Positive Rate (TPR) and overall performance (macroF1score) were ≥0.7. The best performing algorithm was proposed per model for inclusion in the final ML-DST. Data from 20,440 individual OHCs were collected, with the final sample including 3,412 paired sets. Best TPR per model ranged between 0.51 and 0.71, with one model having TPR ≥ 0.7 and macroF1score ≥ 0.7. This model indicated advice about changing nutritional behavior could improve vitality, but the worker profiles created by the model were not conceptually meaningful. For the other 11 models, quantitative performance was not useful. In conclusion, using data from 10-year real-world occupational, health, and personal characteristics to train algorithms for an ML-DST aimed at offering advice on lifestyle changes to improve SE did not result in useful model performance for enhancing workability and vitality.

Finally, in **chapter 8** the studies are integrated and discussed. The relevance of the thesis was to provide innovative support for occupational physiotherapists so they can provide effective advice

related to whether a specific worker in their specific context would benefit from an intervention to improve prospects for SE. The integrated discussion is structured around perspectives on these topics and compared to relevant literature. The designs of the individual studies have various methodological strengths and limitations. Overall, a strength of the PhD study was the inclusion of data from a large number of OHCs with a long follow-up period, which enhances external validity. A strength during the ML-DST development process was the exploration of potential consequences and ethical considerations of using ML-DSTs in the context of occupational health. The insights raised awareness for future use, as well as guiding points to consider during the design of the ML-DST. However, potential limitations include selection bias and the healthy-worker effect. Another limitation was that using real-world data introduced challenges, particularly due to the voluntary nature of both workers and companies. The absence of systematic documentation of non-lifestyle interventions during the study period may have constrained the potential to enhance the advice offered by occupational physiotherapists. Additionally, the choice to operationalize SE through workability and vitality, while excluding employability, may have influenced the results. Based on the results and considerations, directions were provided for future policy, education, research, ML-DST development and occupational physiotherapists. This thesis contributed to knowledge of resilience as a potentially protective factor for SE, which could be used by occupational health professionals when advising for SE. Although the development of an ML-DST to provide advice on what works for whom was not achieved, major lessons were learned. This experience may provide direction for future development of ML-DSTs in the occupational health context aimed at supporting workers to stay at work.