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Relationship between Physical Activity and Aerobic Capacity

in Chronic Lung Disease and in different Occupational Groups

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RELATIONSHIP BETWEEN PHYSICAL ACTIVITY AND AEROBIC CAPACITY IN CHRONIC LUNG DISEASE AND IN DIFFERENT OCCUPATIONAL GROUPS

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Preface

This external dissertation was conducted at the University Hospital Basel and Cantonal Hospital Baselland in Liestal under the supervision of Prof. Dr. med. Jörg Daniel Leuppi, PD Dr. med. David Miedinger and PD Dr. med. Thomas Dieterle. ETH internal support was provided by Prof. Dr. Kurt Murer until his retirement in March 2015 and by his successor Prof. Dr. med. David Paul Wolfer.

The aim of this doctoral thesis was to investigate the relationship between physical activity and aerobic capacity in chronic lung disease and in different occupational groups. Therefore, the thesis is divided into two parts: part I analysed the role of physical activity in patients with chronic obstructive pulmonary disease (COPD), while part II assessed physical activity and aerobic capacity in voluntary healthy employees. The first part was completed at the University Hospital Basel and resulted in a first-author publication, while the second part was conducted at the Cantonal Hospital Baselland in Liestal and resulted in a first-author and a last-author publication.

The PhD candidate Stefanie Gabriele Brighenti-Zogg has made substantial contributions to the conception and design of the work by drafting the study protocols, study management and monitoring, data acquisition, analysis and interpretation. Furthermore, she drafted the manuscripts for the two first-author publications and supervised the writing of the last-author publication resulting in the master thesis of Jonas Mundwiler submitted at the Department of Sport, Exercise and Health at the University of Basel in September 2015.

Collaboration with the University Hospital Basel and the Cantonal Hospital Baselland in Liestal provided access to individuals with COPD and different occupational groups. For part I of this thesis, the authors gratefully acknowledge the financial support received by the foundations ‘Gottfried und Julia Bangerter-Rhyner-Stiftung’, ‘Freiwillige Akademische Gesellschaft Basel’ and ‘Forschungsfonds der Universität Basel’. Part II was financially supported by an unrestricted grant of the Swiss National Accident Insurance Fund (Suva) Lucerne.
List of Abbreviations

AEE: Activity-related energy expenditure
BMI: Body mass index
CAT: COPD assessment test
COPD: Chronic obstructive pulmonary disease
DLW: Doubly-labeled-water method
DOT: Dictionary of Occupational Titles
EE: Energy expenditure
FCEs: Functional capacity evaluations
FEV₁: Forced expiratory volume in one second
FVC: Forced vital capacity
HR\textsubscript{max}: Maximal heart rate
HPA: Physical activity at high intensity
HR\textsubscript{recovery}: Recovery heart rate
HR\textsubscript{rest}: Resting heart rate
HR\textsubscript{max}-to-HR\textsubscript{recovery}: Ratio of maximal to recovery heart rate
HR\textsubscript{max}-to-HR\textsubscript{rest}: Ratio of maximal to resting heart rate
HRQOL: Health-related quality of life
IPAQ: International Physical Activity Questionnaire
LTPA: Leisure-time physical activity
METs: Metabolic equivalents of task
MPA: Physical activity at moderate intensity
MVPA: Physical activity at moderate-to-vigorous intensity
OPA: Occupational physical activity
PAL: Physical activity level
PA\textsubscript{3}: Physical activity duration above 3 METs
RMR: Resting metabolic rate
SD: Standard deviation
SE: Standard error
SWMA: SenseWear Mini armband
WC: Waist circumference
VHPA: Physical activity at very high intensity
VO₂: Oxygen uptake
VO₂\textsubscript{max}: Maximal oxygen uptake
6MWD: 6-minute walk distance
6MWT: 6-minute walk test
Summary

Numerous studies provide evidence for the promotion of physical activity to prevent chronic diseases in healthy subjects and reduce the risk of disease progression in chronically ill patients. In addition, the level of physical activity and the resulting aerobic capacity determine the ability to actively participate in the work process. Moreover, the relation of physical activity to aerobic capacity plays a central role in the reintegration of patients after phases of sick leave. Despite the increasing number of patients in need for reintegration into the work process after diseases or medical procedures, no established reference values exist to evaluate point of time and appropriate way of return to work. Therefore, determining physical performance criteria of different occupational groups appears to be important for assessing the individual work capacity and the ability to take over tasks that are potentially physically demanding. The aim of this thesis was to objectively measure physical activity and aerobic capacity in patients with chronic obstructive pulmonary disease (COPD) (part I) as well as in healthy employees (part II) and to investigate their relationship with regard to quality of life and reintegration into employment.

In a cross-sectional manner, data of 87 stable patients with COPD were analysed in part I, while 303 healthy and full-time employed adults from different occupational groups were investigated in part II. In both parts, physical activity was quantified by the SenseWear Mini armband on seven consecutive days (23 hours/day). Average daily energy expenditure, physical activity level in metabolic equivalents of task (METs), number of steps and physical activity duration at different intensities were analysed. The submaximal level of aerobic capacity was measured by the 6-minute walk test in patients with COPD, while the maximal level (VO$_{2\text{max}}$) was determined with the 20-meter shuttle run test in healthy employees. Independent associations of physical activity parameters with aerobic capacity and health outcomes were examined using multiple linear regression analysis. To determine physical performance criteria of different occupational groups, the ratio between workload as measured by METs and employees’ work capacity as measured by VO$_{2\text{max}}$ was analysed.

In patients with COPD, the number of daily steps and aerobic capacity correlated significantly with each other and were independent predictors of quality of life, whereas no relationship was found with moderate-to-high intensity activity. In contrast, in healthy employees, high-to-very high intensity activity during leisure-time was associated with high aerobic capacity. Neither daily steps nor work-related activity revealed an independent association with VO$_{2\text{max}}$. The ratio of physical workload to maximum work capacity was on average one third of VO$_{2\text{max}}$ and increased from sedentary occupations (21%) to jobs with moderate (29%) and high (44%) physical demands. Women showed an equal absolute workload as men, but had a higher relative workload due to their lower VO$_{2\text{max}}$ (37% vs. 26%). Multiple linear regressions revealed that physical workload correlated positively with moderate-, high- and very high-intensity activity at work, whereas it was negatively associated with flextime, daily working hours, age and VO$_{2\text{max}}$.

The findings of this thesis provide evidence that the relationship between physical activity and aerobic capacity is intensity- and type-specific and varies between impaired and healthy subjects. The results emphasise the need for patients with COPD to maintain physical activity as an integral part of everyday life and to remain mobile, whereas healthy employees need to engage in sufficient high-intensity physical activity in recreation for improving VO$_{2\text{max}}$. This could be explained by the fact that patients with chronic lung disease adopt a sedentary lifestyle and get used to the lower level of physical activity, while healthy subjects may require higher-intensity stimuli to achieve health benefits. Since physical activity
and aerobic capacity are independent predictors of quality of life in patients with COPD, measuring activity and fitness levels should be an integral part of the assessment of patients. This may help to prevent future disease exacerbations by allowing appropriate education or treatment. Regarding the reintegration of patients after phases of sick leave, the determined gender- and job-specific physical performance criteria may help to develop future guidelines for a safe return to work. If an individual’s job profile needs to be adjusted, the present results suggest considering various personal and job-related factors for evaluating physical workload, besides VO$_{2\text{max}}$. This is an important finding, since up to now work recommendations were primarily based on individuals’ aerobic capacity. An optimised reintegration process might have the potential to reduce future loss of working hours and related health care costs. With the increasing availability of big data, prescriptive analytics might in future be able to disrupt the traditional healthcare system by recommending courses of actions and showing likely outcomes based on population-derived values.
Kurzfassung


Bei COPD Patienten korrelierten die aerobe Leistungsfähigkeit und tägliche Schrittzahl miteinander und als unabhängige Prädiktoren mit der Lebensqualität, aber nicht mit moderater bis hochintensiver körperlicher Aktivität. Im Gegensatz dazu war bei gesunden, berufstätigen Personen Freizeitaktivität im hohen bis sehr hohen Intensitätsbereich positiv mit der VO\textsubscript{2max} assoziiert. Weder die Schrittzahl, noch die berufsbegogene körperliche Aktivität zeigten hier einen signifikanten Zusammenhang mit der VO\textsubscript{2max}. Das Verhältnis von körperlicher Arbeitsbelastung zu VO\textsubscript{2max} betrug im Schnitt ein Drittel und stieg von sitzenden Berufen (21%) zu solchen mit mittleren (29%) und hohen (44%) körperlichen Anforderungen an. Frauen hatten die gleiche absolute Arbeitsbelastung wie Männer, jedoch eine höhere relative Belastung aufgrund ihrer tieferen VO\textsubscript{2max} (37% vs. 26%). Bei der multiplen linearen Regressionsanalyse korrelierte die körperliche Arbeitsbelastung positiv mit moderater bis hochintensiver Arbeitsaktivität, und negativ mit Gleitzeit, Arbeitsstunden pro Tag, Alter und VO\textsubscript{2max}.

Die vorliegenden Resultate deuten darauf hin, dass der Zusammenhang zwischen körperlicher Aktivität und aerob Leistungsfähigkeit intensitäts- und typabhängig ist und zwischen kranken und gesunden Personen variiert. Die Ergebnisse legen nahe, dass COPD Patienten im täglichen Leben mobil bleiben müssen, während die gesunde Arbeitsbevölkerung in der Freizeit mit hoher Intensität körperlich aktiv sein sollte, um die VO\textsubscript{2max} zu verbessern. Diese Diskrepanz könnte dadurch erklärt werden, dass Patienten mit chronischer Lungenkrankung einen sitzenden Lebensstil erlangen und sich an das tiefe Aktivitätsniveau gewöhnen. Dagegen benötigen gesunde Personen möglicherweise höhere Belastungs-
Chapter 1: General introduction

1.1 Impact of physical activity on health

Human beings were designed to cover long distances for transport, communication and food acquisition by hunting or gathering. Therefore, skeletal muscles rely on a certain degree of physical activity in order to maintain their function [1]. However, technical progress such as motorisation of transport and associated social changes have led to diminished physical activity in daily life [1]. Earlier generations did on average significantly more physical work than people of today, who adopted a sedentary lifestyle [1]. For example, in the sixties the average English person watched 13 hours of television a week compared to 26 hours in the nineties [2]. While the total amount of physical activity has decreased over the last decades, the daily time period, in which occupational activity is performed, has increased through the inception of light introducing longer working days and night shifts. This paradox might be explained by increasing automation that has facilitated many processes in modern society. Subjects’ work of today is computerised and machine-controlled compared to primarily manual work in the past. In addition, better networking allows collaboration across time zones, in particular for trade and stock market. Physical inactivity has become a major public health concern in industrialised countries and represents the fourth leading risk factor for mortality worldwide [3]. In Switzerland, inactivity causes an estimated 2900 premature deaths and 2.1 million cases of illness per year leading to direct treatment costs of 2.4 billion Swiss Francs [1]. Additional indirect costs result from production and work time losses [1].

Physical activity is one of the key factors for preventing chronic diseases and promoting health. It has been shown to reduce the risk of hypertension, cardiovascular disease, stroke, type 2 diabetes, osteoporosis, colon and breast cancer [3, 4]. Furthermore, a longitudinal study observed a significant association between regular activity and a reduced risk of chronic obstructive pulmonary disease (COPD) among smokers [5]. In addition, physical exercise is essential for energy balance and weight control and provides social and psychological benefits, such as a decreased risk of depression and an increased stress tolerance [3]. In general, active individuals report fewer medical encounters, are less frequently absent from work, have a better health-related quality of life, live longer and are more independent in old age [1, 6].

Since physical activity is a predictor, but also an indicator of a person’s overall health and can change in response to prescribed medication or behavioural interventions, it is valuable to quantify activity levels across populations. Appropriate instruments are required to evaluate the dose-response relationship with health outcomes and to monitor the effect of interventions [7]. However, the multi-dimensional nature of physical activity makes measurement methodologically challenging and currently there is no method to assess all dimensions. Combining multiple devices may therefore be a more suitable approach [8].

1.2 Definition of physical activity

Physical activity is characterised by several dimensions such as type, intensity, frequency and duration [9]. Regarding the type of physical activity, different domains can be distinguished according to the context in which it is practised (e.g. work, leisure-time, transport, domestic and garden) [10]. There are two major categories, occupational physical activity (OPA) and leisure-time physical activity (LTPA) [11]. While OPA is associated with pursuing a job, typically within the time frame of about eight hours, the duration of LTPA is quite variable [11]. LTPA includes daily activities (e.g. walking, hiking, gardening) besides formal exercise programs, which are planned, structured and repetitive in order to maintain or
improve physical fitness [12]. The intensity of physical activity can be determined by metabolic equivalents of task (METs) expressing the energy cost of physical activities as the rate of energy expenditure (EE) above the resting metabolic rate (RMR) [13]. One MET corresponds to RMR, which is the amount of oxygen consumed while sitting quietly per kilogram of body weight, approximately 3.5 ml O$_2$/kg/min in the average adult [13]. Thus, the MET value of a specific activity can be calculated by dividing its relative oxygen cost (ml O$_2$/kg/min) by 3.5 providing a simple and practical measure (Table 1) [13]. Low intensity is defined as less than 3 METs, moderate intensity as 3 to 6 METs, high intensity as 6 to 9 METs and very high intensity as more than 9 METs [14]. However, Kozey et al. [15] have shown that RMR was reduced in the elderly, overweight and females. Thus, the reference of 3.5 ml O$_2$/kg/min may be too high in these subgroups resulting in underestimated METs, which could be corrected by using a height-, weight- and age-adjusted reference [15]. Frequency indicates the number of physical activity sessions during a specific time period, while duration is the amount of time spent in an activity session.

Table 1: METs for various sport activities, according to Ainsworth et al. [14]

<table>
<thead>
<tr>
<th>Activity</th>
<th>MET value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gardening</td>
<td>3</td>
</tr>
<tr>
<td>Walking</td>
<td></td>
</tr>
<tr>
<td>leisurely</td>
<td>3</td>
</tr>
<tr>
<td>normal</td>
<td>3.5</td>
</tr>
<tr>
<td>brisk</td>
<td>4</td>
</tr>
<tr>
<td>Hiking</td>
<td>5</td>
</tr>
<tr>
<td>Stairs climbing</td>
<td>6</td>
</tr>
<tr>
<td>Jogging</td>
<td>7</td>
</tr>
<tr>
<td>Marathon (~ 10 km/h)</td>
<td>10</td>
</tr>
<tr>
<td>Cycling</td>
<td></td>
</tr>
<tr>
<td>leisurely</td>
<td>4</td>
</tr>
<tr>
<td>normal (~ 100 Watt)</td>
<td>5.5</td>
</tr>
<tr>
<td>fast</td>
<td>6</td>
</tr>
<tr>
<td>Professional cycling (~ 25 km/h)</td>
<td>10</td>
</tr>
<tr>
<td>Mountain biking</td>
<td>8.5</td>
</tr>
<tr>
<td>Swimming</td>
<td>6</td>
</tr>
<tr>
<td>Basketball</td>
<td>6</td>
</tr>
<tr>
<td>Soccer</td>
<td>7</td>
</tr>
<tr>
<td>Handball</td>
<td>8</td>
</tr>
<tr>
<td>Volleyball</td>
<td>4</td>
</tr>
<tr>
<td>Aerobics</td>
<td>6.5</td>
</tr>
<tr>
<td>Strength training</td>
<td>4.5</td>
</tr>
<tr>
<td>Martial arts</td>
<td>10</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>6.5</td>
</tr>
<tr>
<td>Yoga</td>
<td>3.5</td>
</tr>
<tr>
<td>Jazz dance</td>
<td>5</td>
</tr>
<tr>
<td>Golf</td>
<td>4.5</td>
</tr>
<tr>
<td>Badminton</td>
<td>4.5</td>
</tr>
<tr>
<td>Squash</td>
<td>12</td>
</tr>
<tr>
<td>(Ice-) Skating</td>
<td>7</td>
</tr>
<tr>
<td>Horse riding</td>
<td>4</td>
</tr>
</tbody>
</table>

METs, metabolic equivalents of task. METs express the rate of energy expenditure above the resting metabolic rate. 1 MET = 3.5 ml O$_2$/kg/min.
Physiologically, physical activity is defined as any bodily movement produced by skeletal muscles that increases EE above the basal level [12]. Muscles are made up of two distinct types of muscle fibers, which generate adenosine triphosphate (ATP) supplying energy for muscle action in a different way [16]. Fast-twitch (FT) muscle fibers have a rapid contraction speed and a high capacity for anaerobic ATP production via glycolysis [16]. In contrast, slow-twitch (ST) muscle fibers with a slow contraction speed and high resistance to fatigue generate ATP primarily through aerobic pathways [16]. In general, it can be distinguished between aerobic and anaerobic activity depending on oxygen availability for ATP production. Aerobic activity mainly involves ST muscle fibers and uses oxygen to burn fat and carbohydrates for producing ATP [16]. It can be sustained for long periods at low-to-moderate intensity, is rhythmic in nature and activates large muscle groups. Anaerobic activity mostly uses FT muscle fibers, targets individual muscles, burns carbohydrates in the absence of oxygen and can be sustained only for short periods at high-intensity due to accumulation of lactic acid as by-product [16]. EE measures are considered as indirect estimates of physical activity, as they are shaped by sex, age and body mass [17].

1.3 Measurement of physical activity

In epidemiological studies, instruments to measure physical activity need to be valid, reliable, practicable and non-reactive [18], the latter meaning that subjects do not change their activity behaviour in response to the measurement. However, currently no instrument fully meets all of these criteria [18]. Highly accurate methods tend to be expensive and inappropriate for widespread use [18]. In contrast, low costs and good practicability are counteracted by a lower validity [18]. Thus, the selection of a suitable device always represents a compromise and needs to be adapted to the current research context. Numerous methods to measure physical activities are available. In general, methods can be categorised into three groups [19]:

- Criterion methods e.g. doubly-labeled-water (DLW), indirect calorimetry, direct observation
- Objective methods e.g. pedometers, accelerometers, heart rate (HR) monitors
- Subjective methods e.g. questionnaires, diaries, activity logs

These techniques differ in terms of accuracy, costs, measurable sample size, required time and effort, as well as technical limitations [19].

Criterion methods remain the gold standard for quantitative assessment of EE [19]. However, they are infrequently applied in clinical research because they are expensive, time- and labour-intensive, not suitable to capture qualitative data and do require specialised training [19]. Nevertheless, these techniques provide useful methods for validating other instruments (e.g. self-report questionnaires and portable electronic devices) to measure physical activity in the general population [19].

Subjective methods, such as self-report questionnaires, may be the most suitable method for physical activity assessment in clinical settings. They are cost effective, easy to administer and non-reactive [20]. However, they vary by what they measure (e.g. type, duration or frequency of physical activity), how data are reported (e.g. activity scores, time, calories), as well as the quality of data (e.g. levels of intensity, inclusion of work and non-work related activity) [8, 21]. In addition, they vary with regards to the method how data are obtained (e.g. paper and pencil assessment, computerised questionnaire and interview). Furthermore, they rely on participants’ recall ability and may be limited by the dependency on internal factors, such as subjective interpretation and perception, as well as external factors including social desirability, age and sex [19, 22]. Since many self-report instruments do not account for activities with an exertion level below brisk walking, they are less robust in measuring low-to-moderate intensity activity [23]. Validation studies in adults comparing self-report (subjective) to direct (criterion, objective)
measures are inconsistent. A systematic review including 173 articles found that self-report data were both higher and lower than directly measured activity levels and revealed weak-to-moderate correlations [24].

Objective methods are supposed to provide more accurate estimates of physical activity and EE and remove the issue of a recall bias [24]. In contrast, as a reactive measure they may induce changes in subjects’ activity behaviour during the measurement period. Pedometers are small, simple and inexpensive devices to measure the number of steps taken with a horizontal, spring-suspended lever arm, which is deflected when the subject’s hip accelerates vertically with a force beyond a chosen threshold [8]. Pedometers were found to correlate strongly with uniaxial accelerometers and directly observe time spent in activities [25]. In contrast, they do not record intensity and frequency of physical activity or purely upper body movements and cycling [26]. Moreover, pedometers are known to be compromised in accuracy at slow walking speeds [25]. Accelerometers have gained popularity given their improved accuracy and data storage capacity compared to pedometers [26]. Accelerometers can be worn on different body locations, such as waist, hip and thigh. They record acceleration (counts) in real time and detect movement in up to three orthogonal planes [27]. These counts are then translated into estimates of physical activity or EE by using linear regression equations [19]. Triaxial accelerometers have been shown to be reliable and sensitive to changes in movement speed [28]. However, they are limited in assessing EE associated with complex activities (e.g. carrying a load) and static events (e.g. standing vs. sitting) [27]. HR monitoring is an objective but indirect method for measuring physical activity and EE based on the linear relationship between HR and oxygen uptake (VO$_2$) during a wide range of aerobic exercise [29]. It provides data on frequency, duration and intensity of physical activity for periods of up to one month [20]. By capturing EE during activities not involving vertical trunk displacement, such as rowing and cycling, HR monitors can overcome limitations of accelerometers and pedometers [30]. As a weakness, they show deviations from real data particularly at low and very high intensity, which result from non-linear relationships between HR and VO$_2$ at these intensities [29]. Moreover, HR is affected by stress, medication and environmental factors (e.g. temperature, humidity), and the correlation with EE may be influenced by age, gender and fitness level [30, 31].

To address limitations of conventional devices, armband technology has been developed [32]. Several versions of the armband exist including SenseWear, HealthWear or Bodybogg, which use motion and heat-related sensors to measure physical activity and EE [8, 31]. This dual measurement strategy is more sensitive for detecting subtle increases in EE and promises an accurate assessment of daily physical activities under free-living conditions [32]. Armbands have been shown to be excellent devices for assessing everyday tasks, but are less accurate in measuring higher intensity exercise [33].

The SenseWear Mini armband (SWMA) developed by BodyMedia Inc., Pittsburgh, Pennsylvania, USA (now Jawbone Inc., San Francisco, California, USA) (Figure 1) was found to provide more precise estimates of EE during low-to-moderate intensity semi-structured activities compared to other devices [34]. It has been validated in healthy subjects as well as in patients with chronic diseases. In healthy adults, a validation study against DLW showed a high intraclass correlation ($r=0.85$, 95% confidence interval: 0.92-0.76) and a low absolute error rate (8%, 7) [32]. The sensitivity of the SWMA to detect small but important changes in EE during everyday activities was confirmed in patients with COPD and rheumatoid arthritis when compared to indirect calorimetry [35, 36].
This small and wireless multisensory activity monitor integrates motion data from a three-axis accelerometer along with other physiological sensors, such as heat flux, skin temperature and galvanic skin response (Figure 2) [31]. Heat flux is measured using a propriety sensor that incorporates low thermal-resistant material and thermocouple arrays. Galvanic skin response is measured by two hypoallergenic stainless steel electrodes and assesses the degree of evaporation heat loss. Skin temperature is used to account for core body temperature and is measured using a thermistor-based sensor.
The combination of multiple sensors enables the SWMA to assess EE associated with load carrying and to distinguish between acceleration provoked by muscle power or externally by a motor or gravitation [31]. However, the SWMA seems to be inaccurate in estimating EE during activities involving uphill and downhill walking [37]. The physiological data collected by the armband’s sensors are processed by specific algorithms available in the SWMA software (BodyMedia, professional software V.7.0, algorithm V.2.2.4). Subjects’ average daily EE, number of steps, physical activity duration at different intensities and physical activity level (PAL) are calculated. PAL as a measure of average daily METs is calculated as total daily EE divided by whole-night sleeping EE [38]. A PAL of ≥1.70 METs defines an active person, 1.40-1.69 METs a predominantly sedentary person and <1.40 METs a very inactive person [39].

Generally, the armband is worn on the upper left arm (triceps area) for seven consecutive days (23 hours/day) with the exception of one hour daily spent on personal hygiene. The SWMA can be comfortably worn while sleeping, exercising and in daily routine, as the slim design minimizes interference with day-to-day activity [31]. Furthermore, the recording of non-wearing, resting and sleep time allow for more confidence in data consistency. However, the SWMA has been shown to underestimate activities at high intensities and those involving purely lower extremities, such as cycling, because of its wearing position on the upper arm [33, 40]. In addition, it is not waterproof and lacks to detect water-based activities. Since the SWMA is not explosion protected (not marked with ATEX-RL 94/9/EG), it cannot be applied in highly explosive environments. This limits its use in the investigation of individuals, who work in spaces with potentially explosive atmospheres.

1.4 Global recommendations on physical activity

Based on the close relationship between physical activity and health, governmental and non-governmental agencies have developed global activity guidelines to prevent chronic diseases and improve physical fitness. The World Health Organization (WHO) recommends adults between 18 and 64 years to engage in at least 150 minutes of moderate-intensity or at least 75 minutes of high-intensity aerobic activity throughout the week [10]. Moderate intensity is associated with slightly increased breathing and corresponds to brisk walking, cycling or gardening, whereas high intensity significantly accelerates breathing and includes vigorous leisure-time and sport activities [10]. It is advisable to combine and vary between activities from different domains, which should be performed in bouts of at least 10 minutes duration [10]. In addition, muscle-strengthening exercises should be performed involving large muscle groups at least twice per week [10]. In Switzerland, self-report questionnaire data from the latest Swiss Health Survey 2012 showed that 28% of adults were either insufficiently active or entirely inactive, when measured against the minimum WHO recommendation per week [41].

1.5 Effects of physical activity on aerobic capacity

Sufficient and regular physical activity has been shown to increase individuals’ aerobic capacity and physical fitness, which may provide various health benefits [19, 42]. When exercising, muscles have a higher demand for oxygen with regard to ATP production. In consequence, breathing and heart rate are getting faster and blood flow to working muscles is increased. The small blood vessels called capillaries are widened to deliver oxygen more efficiently to the muscle fibers and carry away waste products, such as carbon dioxide and lactic acid. With aerobic training, the number of capillaries surrounding the working muscle fibers has been shown to increase by more than 15% improving blood perfusion [43]. Aerobic activity predominantly involves ST muscle fibers with a high oxidative capacity. When entering the muscle fibers, oxygen binds to myoglobin, whose content increases by about 80% with training [43]. Fat stored as triglyceride supplies the primarily fuel in the presence of oxygen at submaximal intensity,
but also carbohydrates stored as glycogen are burned [43]. In response to regular exercise, muscular triglyceride and glycogen stores at rest are increased [43]. In addition, the mitochondria responsible for ATP production increase in both size and number and activities of mitochondrial oxidative enzymes are enhanced [43]. With repeated aerobic activity, the integrated response of diverse physiological systems is improved (e.g. pulmonary ventilation and diffusion ↑, cardiac output ↑, haemoglobin concentration ↑, peripheral blood flow ↑, cellular metabolic capacity ↑), which contributes to an increase of oxygen utilisation and consequently to an improved aerobic capacity [44].

1.6 Definition and determinants of aerobic capacity

Maximal oxygen uptake (VO2max) is defined as the maximal volume of oxygen that can be utilised in one minute during maximal or exhaustive exercise [45]. It is measured in milliliters of oxygen consumed per kilogram of body weight per minute [45]. VO2max is generally accepted as the most valid and reliable index of aerobic capacity or cardiorespiratory fitness [46]. It reflects one of five components of health-related physical fitness (cardiorespiratory endurance, muscular endurance, muscular strength, body composition and flexibility) that relates to the ability of the cardiovascular and respiratory systems to supply oxygen during sustained physical activity [12, 47]. In prospectively conducted longitudinal studies, a low VO2max was found to be a strong and independent predictor for the incidence of various diseases, such as hypertension, stroke, type 2 diabetes and metabolic syndrome [48, 49]. Besides physical activity, VO2max is depending on genetics, age, gender, body fat, smoking and medical conditions; it is usually higher in males than in females and declines with age, increasing overweight and smoking [50, 51]. The ability of an individual to increase VO2max is inherited and thus genetically limited. Each individual disposes of a predetermined genetic window and can vary the amount of VO2max with exercise training or detraining within that window [52]. VO2max can range from values below 20 ml/kg/min in poorly conditioned adults to 80-90 ml/kg/min in world-class runners and cross-country skiers [45]. There are two opposing theories on the limitation of VO2max: one identifying insufficient concentration of oxidative enzymes in the mitochondria as limiting factor, and one focusing on central and peripheral circulatory factors [52]. The second theory is strongly supported by evidence stating that oxygen transport to the muscles, rather than oxidative enzymes in the mitochondria limits VO2max [52].

1.7 Measurement of aerobic capacity

Direct measurement of VO2max by incremental exercise testing with spiroergometry is considered to be the gold standard to determine aerobic capacity [19]. Exercise testing should involve large muscle groups in order to activate the cardiorespiratory gas transport system. This is guaranteed by ergometers, such as treadmill and cycle ergometers. A breathing mask collects the inhaled and exhaled air at each breath for respiratory analysis, which ensures an accurate determination of oxygen uptake and carbon dioxide production [53]. However, direct measurement of VO2max is labour-intensive, requires trained staff and is therefore not feasible for assessing large populations [54].

A simple field test to provide an estimate of VO2max is the multistage 20-meter shuttle run (Figure 3), which evaluates the maximal aerobic capacity of healthy adults [55]. It is practical in use, economical and large groups can be tested simultaneously. Subjects have to run back and forth between two lines, which are 20 meters apart, with a running velocity determined by audio signals [55]. Starting speed is 8.5 km/h and every minute (stage), speed is increased by 0.5 km/h until the subject can no longer keep the pace and does not reach the lines in time twice in a row [55]. The test result corresponds to the number of reached stages and shuttles and is used to predict VO2max according to a validated table [56].
Validity of the one-minute stage version of the 20-meter shuttle run test was established by Léger & Gadoury [57], who compared the maximal shuttle run speed to VO$_{2\text{max}}$ attained during a multistage treadmill test ($r=0.90$). A recent study also revealed significant correlations between the number of achieved shuttles in the 20-meter shuttle run test and directly measured VO$_{2\text{max}}$ ($r=0.87$, $p<0.05$) as well as the velocity at which VO$_{2\text{max}}$ occurred ($r=0.93$, $p<0.05$) [58]. However, practice and motivation may influence the number of reached shuttles. Environmental conditions could also affect the results, as the test is often conducted outside. Since the 20-meter shuttle run is a maximal exercise test requiring maximum effort, it is not suitable for individuals with illnesses, injuries or low fitness levels.

The 6-minute walk test (6MWT) represents an adequate method to objectively determine aerobic capacity in patients with impaired health (Figure 4) [59]. It measures the distance that a patient can quickly walk on a flat, hard surface in the period of six minutes [59]. This test assesses the global and integrated responses of all organ systems involved during exercise and has been shown to be a good predictor of functional status in patients with chronic lung disease [59, 60]. The 6MWT is performed indoors, easy to administer and well tolerated. Patients choose their own intensity and are allowed to stop and rest during test [59]. Thus, it is a self-paced test assessing the submaximal level of aerobic capacity, which may well reflect daily physical activities [59]. Research provides evidence for conducting two tests per patient, because a learning effect may occur between the first and second test [61].
1.8 Relationship between physical activity and aerobic capacity

When individuals get ill and develop a chronic condition, they are impaired in their daily routine and work ability. Affected people are often not able to continue their job. For example, patients with COPD suffer from exertional dyspnea, even when performing everyday tasks, and adopt a sedentary lifestyle [38]. This might support the fact of symptom-induced inactivity. However, inactivity itself can also lead to physical deconditioning and loss of aerobic capacity, which in turn increases exertional dyspnea [62].

To break this vicious cycle of decline (Figure 5), exertional dyspnea needs to be reduced. And this can only happen, when patients remain active in daily life. However, there is a risk that patients get used to the lower level of daily activity and thus their functions continue to decline. Since healing is not possible in patients with COPD, it is a major goal to improve their health-related quality of life. Regular physical activity was found to reduce the risk of hospital admissions due to COPD exacerbations [63]. Furthermore, physical exercise has been shown to increase functional aerobic capacity and to relieve symptoms, such as dyspnea and fatigue [64]. Several studies have confirmed positive correlations of physical activity and aerobic capacity with health-related quality of life in patients with COPD [65, 66]. However, for clinical practice, it might be important to identify their independent impact on health by conducting multivariate analyses. A distinction is relevant, because physical activity is a behaviour, whereas aerobic capacity is a physiological measure reflecting a combination of activity behaviour, genetic potential and functional health [67]. Moreover, in the above studies, physical activity was recorded by self-administered questionnaires and therefore an accurate assessment of the effect of physical activity on quality of life was not possible. Since measurement uncertainties could lead to difficulties in developing effective intervention strategies, future studies are required using objective methods to accurately capture daily physical activity in impaired patients.

![Figure 5: Vicious cycle of decline between inactivity associated with physical deconditioning, decreasing aerobic capacity and increasing exertional dyspnea [62].](image)

In healthy subjects, regular physical activity is essential for preventing chronic diseases and improving physical fitness. According to current guidelines, aerobic activities should be performed for a minimum duration of 10 minutes across different domains, such as work, leisure-time, transport, domestic and garden [10]. Since most people in full-time employment spend one third or more of the day at work, it is conceivable that OPA may contribute to a large extent to total daily activity. While LTPA is well known to be positively associated with VO₂max [68], only few data are available on the relationship between OPA and VO₂max.
Previous studies measuring physical activity in employees used pedometers or accelerometers in combination with self-report questionnaires [69, 70]. Step counting using pedometers or accelerometers is widely accepted for assessing the amount of physical activity [71]. However, an accurate assessment of task-specific activities is not possible using these instruments, which might be essential to evaluate the impact of OPA on VO\(_{2}\)\(_{\text{max}}\). Miller & Brown [69] confirmed that measuring OPA can be challenging because of the intermittent and unstructured nature of most work-related activities. Due to methodological limitations and lack of studies, potential associations of work and non-work related physical activity with aerobic capacity in employees still need to be clarified by further investigations.

For individuals recovering from an illness, it is important to return to everyday life and resume work as soon as possible. Work does not only provide wage incentives, it has further benefits including a well-ordered structure of the day and the need for physical activity. When reintegrating patients into the work process after phases of sick leave, it might be necessary to assess their work ability in order to adequately adjust the job profile. The knowledge of workload and required work capacity could facilitate this process, because a successful resumption of work is highly dependent on these factors [72]. Since physical workload differs considerably between job assignments, it is valuable to analyse a wide range of physical work requirements and to assess employees’ aerobic capacity across occupational groups. Although several attempts have been made in this regard, there are few objective data available so far and no established reference values exist to evaluate point of time and appropriate way of return to work [73]. Therefore, further investigations need to determine job-specific physical performance criteria in healthy employees, which may help to develop future guidelines for a safe return to work.

1.9 Aims and outline of this thesis

The aim of this doctoral thesis was to investigate the relationship between objectively measured physical activity and aerobic capacity in people with chronic lung disease (part I) and in different occupational groups (part II), in order to evaluate how physical activity as a behaviour and physical fitness as a resulting capacity influence health and determine the individual ability to actively participate in the work process. It remains still unclear what activity type and intensity is needed to improve functional and health status in both chronically ill as well as healthy working subjects. Moreover, despite the increasing number of patients in need for reintegration into employment after sick leave or medical procedures, no established reference values exist to evaluate point of time and appropriate way of return to work. Therefore, determining physical performance criteria of different occupational groups appears to be important to provide the basis for guiding occupational rehabilitation measures. Clarifying these aspects could be beneficial to specify and optimise intervention strategies involving exercise and might provide important results for the areas of prevention and rehabilitation.

Part I analysed the independent association of daily physical activity parameters (EE, METs, number of steps, activity duration at different intensities) quantified by the SWMA and aerobic capacity measured by the 6MWT with health-related quality of life in patients with COPD (chapter 2). In part II, the relationship of work and non-work related EE, METs, number of steps and activity duration at different intensities with aerobic capacity determined by the 20-meter shuttle run was investigated in healthy employees (chapter 3). Furthermore, physical performance criteria of different occupational groups were determined based on objectively measured workload (METs) and work capacity (VO\(_{2}\)\(_{\text{max}}\)) in real-life workplaces (chapter 4). Chapter 5 reviews the main findings of this thesis in the context of the current literature, and discusses their implications for future research.
1.10 References


Part I

Chapter 2: Daily physical activity, functional capacity and quality of life in patients with COPD


Authors Selina Dürr and Stefanie Zogg contributed equally to this manuscript.

2.1 Abstract

Introduction: In the therapy of chronic obstructive pulmonary disease (COPD), it is a major goal to improve health-related quality of life (HRQOL). Patients with COPD often suffer from exertional dyspnea and adopt a sedentary lifestyle, which could be associated with poorer HRQOL. The aim of this study was to investigate the independent association of objectively measured daily physical activity and functional capacity with HRQOL in patients with COPD.

Methods: In this cross-sectional study conducted at the University Hospital Basel, Switzerland, 87 stable patients (59% male, mean age: 67 yrs, SD 10, range 44-90 yrs) with COPD in GOLD grades I (n=23), II (n=46), III (n=12) and IV (n=6) were investigated. To assess HRQOL, the COPD assessment test (CAT) was completed. Patients performed spirometry and 6-minute walk test. Physical activity was measured by the SenseWear Mini armband on seven consecutive days. By performing a multiple linear regression analysis, independent predictors of CAT score were identified.

Results: Age (β=-0.39, p=0.001), average daily steps (β=-0.31, p=0.033) and 6-minute walk distance (β=-0.32, p=0.019) were found to be independent predictors of CAT score, whereas physical activity duration above 3 METs (p=0.498) and forced expiratory volume in one second in percent of predicted (p=0.364) showed no significant association.

Conclusions: This study showed that average daily steps and functional capacity are independent determinants of HRQOL in patients with COPD. This emphasises the importance to remain active and mobile, which is associated with better HRQOL.

2.2 Introduction

Chronic obstructive pulmonary disease (COPD) is characterised by progressive and not fully reversible airflow limitation [1]. Patients with COPD are known to adopt a sedentary lifestyle [2]. Moreover, physical activity level (PAL), average daily steps and 6-minute walk distance (6MWD) decline with increasing severity grades [3]. However, inactivity itself can also lead to further deconditioning and loss of functional capacity, which in turn increases exertional dyspnea and ends in a vicious cycle of decline [4].

Health-related quality of life (HRQOL) is associated with all-cause and respiratory mortality in patients with COPD [5]. In this incurable chronic disease, it is a major goal to maintain and improve HRQOL. Therefore, identifying its predictors may be valuable for clinical practice. In previous studies, HRQOL was found to be influenced by age and disease severity [6] and a moderate correlation between 6MWD and HRQOL was detected [7]. In addition, inactive patients showed more dyspnea and a poorer HRQOL [8]. Moreover, PAL was identified to be the most important factor for HRQOL in patients with COPD [9]. However, it is still unclear, whether daily physical activity and functional capacity are independent predictors of HRQOL, when the effects of all other investigated predictors are held constant. Moreover, in these studies, physical activity was assessed by self-administered questionnaires and therefore, an
accurate assessment of the effect of physical activity on HRQOL was not possible. Furthermore, the use of complex HRQOL assessment tools may not be feasible in clinical practice. The COPD assessment test (CAT) is a short HRQOL assessment tool, which may be better suited to clinical settings.

The associations of HRQOL, as measured by CAT, with objective daily physical activity parameters, as measured by the SenseWear Mini armband (SWMA), have not been investigated so far. Therefore, the primary aim of the present study was to examine the independent association of objectively measured daily physical activity and functional capacity with CAT-based HRQOL in patients with COPD. The secondary objective was to assess the effect of demographic factors on HRQOL including gender, age, body mass index (BMI), lung function, smoking status, number of comorbidities and number of exacerbations during the past year.

2.3 Methods

2.3.1 Study subjects

From July 2011 to January 2012, patients with COPD were recruited from a patient-file database of the University Hospital Basel, Switzerland. These patients were called and invited for study participation by a member of the research team. Out of 248 approached patients, 91 agreed to participate in this study (Figure 1). Reasons for refusal were: no interest, poor general condition, current hospitalisation and insufficient knowledge of the German language. Eighty-seven clinically stable patients with COPD in GOLD grades I (n=23), II (n=46), III (n=12) and IV (n=6) were finally investigated. Exclusion criteria were COPD exacerbations within the last 30 days and pregnancy, because a computed tomography was performed in another part of this study. The present investigation was approved by the local ethics committee (EKBB, 163/11) and written informed consent was obtained from all subjects.

![Flowchart of study subjects](image)

Figure 1: Flowchart of study subjects. *COPD was defined as the post-bronchodilator FEV₁/FVC ratio <0.70.

COPD, chronic obstructive pulmonary disease; FEV₁, forced expiratory volume in one second; FVC, forced vital capacity.
2.3.2 Study design and procedures

In this cross-sectional study, the Swiss German version of CAT was administered to the patients in order to measure HRQOL. Then, spirometry and 6-minute walk test (6MWT) were carried out to assess lung function and functional capacity, respectively. In addition, several demographic factors were recorded. Finally, patients were instructed to wear the SWMA for the subsequent week in order to quantify daily physical activity.

2.3.3 Measurements

Health-related quality of life

CAT was used to assess HRQOL, since it is a reliable and valid questionnaire, which was found to correlate strongly with the COPD-specific version of the St. George’s Respiratory Questionnaire (SGRQ) \( r=0.80, p<0.001 \) [10]. The advantage of CAT compared to SGRQ is that it is short and less complex, which facilitates its use in routine clinical practice. CAT consists of eight items, each presented as a semantic six-point differential scale, providing a total score ranging from 0-40 [10]. Scores of 0-10, 11-20, 21-30, 31-40 represent a low, medium, high and very high impact on HRQOL, respectively [10]. The content of CAT covers daily symptoms, such as cough, phlegm and chest tightness as well as other manifestations of COPD like breathlessness going up hills/stairs, activity limitation at home, confidence in leaving home, sleep and energy [10].

Lung function

Spirometry was performed according to the guidelines of the American Thoracic and European Respiratory Societies [11]. The EasyOne spirometer (ndd Medizintechnik AG, Zürich, Switzerland) was used to assess lung function before and 15 minutes after inhalation of 200 µg fenoterol. The fixed post-bronchodilator ratio of forced expiratory volume in one second (FEV\(_1\)) to forced vital capacity (FVC) <0.70 was used as criterion for airflow limitation [1].

Functional capacity

6MWT was conducted once by every patient on a 30 meter long flat corridor according to current guidelines [12]. This submaximal test measures the global and integrated responses of all organ systems involved during exercise and represents a good predictor of functional status in patients with chronic respiratory disease [12, 13]. Furthermore, 6MWT was found to be an important parameter related to morbidity and mortality in COPD [14, 15]. Cote et al. [16] have shown that a 6MWD less than 350 meters predicts mortality in patients with COPD. Two patients performed 6MWT with supplemental oxygen and one patient used a rollator. Another six patients used a walking stick.

Patients’ characteristics

The number of COPD exacerbations in the previous 12 months was determined by asking the patients and consulting the hospital medical file. An exacerbation was defined as a worsening of the subject’s condition beyond normal day-to-day variations that required additional treatment with oral or intravenous corticosteroids or antibiotics [17]. Age, gender, height, weight, handedness, smoking status (yes, no more, never) and current medication were recorded and BMI was calculated. The number of comorbidities was documented by accessing the hospital medical file.
Daily physical activity

Daily physical activity was measured by the SWMA developed by BodyMedia Inc., Pittsburgh, Pennsylvania, USA (now Jawbone Inc., San Francisco, California, USA). It integrates motion data from a three-axis accelerometer along with several other physiological sensors such as heat flux, skin temperature and galvanic skin response [18]. In patients with COPD, validity and reliability of the SWMA were established by Hill et al. [19].

Participants were instructed to wear the SWMA on the left arm (triceps) for seven consecutive days, except during water-based activities. The patients were told that the off-body duration of the armband should not exceed one hour a day. To ensure a standardized procedure, the first and the last incomplete measurement day, including the study visits, were not taken into account. Therefore, the investigated measurement period was five days (three weekdays and two weekend days). Reliability of this assessment period has been previously shown [20]. Patients with a wearing time of less than five days and less than 12 hours per day (from wake-up time to 12 hours after waking) were excluded from analyses [21, 22].

The physiological data, collected by the armband’s sensors, were processed by specific algorithms available in the SWMA software (BodyMedia, professional software V.7.0, algorithm V.2.2.4). Age, gender, height, weight, handedness and smoking status were also considered in these calculations. Patients’ average daily number of steps, physical activity duration above 3 METs (PA3) and PAL were examined. One MET defined as metabolic equivalent of task and expressing the energy cost of physical activity corresponds to 3.5 ml O2/min/kg [11]. PAL, calculated as average daily METs, is defined as total daily energy expenditure divided by whole-night sleeping energy expenditure [2]. A PAL of ≥1.70 METs defines an active person, 1.40-1.69 METs a predominantly sedentary person and <1.40 METs a very inactive person [3].

2.3.4 Missing data

In two patients, severity grades were determined with pre-bronchodilator data. In these patients, asthma was excluded by asking the patients, if they had been previously diagnosed with asthma, and by looking at prior diagnoses of asthma in the medical file. Four patients did not complete the 6MWT because of several contraindications including angina pectoris, systolic blood pressure >180 mmHg associated with myocardial infarction in the last 12 months and fractures of lower extremities. In nine patients, SWMA data were missing for one or more days and they were therefore excluded from the corresponding analyses.

2.3.5 Statistical analysis

The main outcome measures were total CAT score, average daily steps, PA3, PAL and 6MWD. Data were analysed using the SPSS software package (version 19.0, IBM, Germany). Significance was set at the 5% level. The Shapiro-Wilk test was used to test whether data were normally distributed. Patients’ characteristics are presented as mean and standard deviation (SD) or number and percentage. To analyse differences in CAT score across categories of PAL and 6MWD, mean comparisons were performed using Mann-Whitney test or Kruskal-Wallis test, if appropriate. Furthermore, Pearson correlations were calculated for parametric data and Spearman correlations for non-parametric data. For multiple linear regression analysis, the forced entry method was used. To ensure the overall fit of the model, Green [23] suggested a sample size of 50 + 8k, where k is the number of predictors. With this rule, a medium effect size is achieved when using a power of 0.80 [24]. Therefore, we included five
predictors in the regression analysis. The dependent variable was total CAT score and all predictors showed a significant bivariate correlation with CAT score, namely average daily steps, PA₃, 6MWD, age and FEV₁ in percent of predicted (FEV₁%predicted). The model was checked for multicollinearity of independent variables. Therefore, PAL was not considered in the analysis due to its high collinearity with PA₃ (r=0.93, p<0.001).

2.4 Results

2.4.1 Patients’ characteristics

Patients’ characteristics are presented in Table 1. Age ranged from 44 to 90 years. Almost half of the patients were current smokers, while 40 (46%) patients had stopped smoking and only 6 (7%) patients had never smoked in their life. Regarding the distribution of patients across the four CAT categories, most subjects were found to have a low (n=36; 41%) and medium (n=41; 47%) impact on HRQOL, whereas only a few individuals were in the categories with high (n=8; 9%) and very high (n=2; 2%) impact on HRQOL.

Table 1: Characteristics of the 87 study participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>N (%) or Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>51 (59)</td>
</tr>
<tr>
<td>Current smokers</td>
<td>41 (47)</td>
</tr>
<tr>
<td>≥1 exacerbations within past year</td>
<td>25 (29)</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>67 (10)</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>26 (5)</td>
</tr>
<tr>
<td>CAT score</td>
<td>13 (7)</td>
</tr>
<tr>
<td>FEV₁predicted [%]¹</td>
<td>69 (24)</td>
</tr>
<tr>
<td>FEV₁/FVC [%]¹</td>
<td>53 (14)</td>
</tr>
<tr>
<td>Average daily steps ²</td>
<td>4784 (3338)</td>
</tr>
<tr>
<td>Average daily PA₃[min] ²</td>
<td>95 (84)</td>
</tr>
<tr>
<td>Average daily PAL [METs]²</td>
<td>1.3 (0.3)</td>
</tr>
<tr>
<td>6MWD [m]³</td>
<td>436 (104)</td>
</tr>
</tbody>
</table>

BMI, body mass index; CAT, COPD assessment test; FEV₁predicted, forced expiratory volume in one second of predicted; FVC, forced vital capacity; METs, metabolic equivalents of task; PAL, physical activity level; PA₃, physical activity duration above 3 METs; SD, standard deviation; 6MWD, 6-minute walk distance.¹ (n=85); ² (n=78); ³ (n=83).

In Table 2, CAT score is divided into categories of PAL and 6MWD. More than half of the patients were very inactive in daily life (PAL <1.40), while the majority of patients achieved a 6MWD of at least 350 meters. Patients, who walked less than 350 meters in the 6MWT showed a significantly higher CAT score than those able to walk 350 meters or more (p=0.019). No significant differences in CAT score were found between categories of PAL (p=0.144).
Table 2: Means of CAT score across categories of PAL and 6MWD

<table>
<thead>
<tr>
<th>Variable</th>
<th>N (%)</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily PAL [METs]¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1.40 METs</td>
<td>45 (58)</td>
<td>14 (7)</td>
</tr>
<tr>
<td>1.40-1.69 METs</td>
<td>24 (31)</td>
<td>11 (7)</td>
</tr>
<tr>
<td>≥1.70 METs</td>
<td>9 (12)</td>
<td>17 (11)</td>
</tr>
<tr>
<td>6MWD [m]²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;350 m</td>
<td>15 (18)</td>
<td>16 (7)</td>
</tr>
<tr>
<td>≥350 m</td>
<td>68 (82)</td>
<td>12 (7)</td>
</tr>
</tbody>
</table>

CAT, COPD assessment test; METs, metabolic equivalents of task; PAL, physical activity level; SD, standard deviation; 6MWD, 6-minute walk distance. ¹ (n=78); ² (n=83).

2.4.2 Correlations of physical activity and functional capacity with quality of life

Table 3 illustrates that the three SWMA parameters and 6MWD were all significantly associated with CAT score. Average daily steps showed the strongest correlation with HRQOL. In addition, age (r=-0.21, p=0.026) and FEV₁%predicted (r=-0.32, p=0.002) were found to correlate significantly with CAT score, while the number of comorbidities (p=0.056), the number of exacerbations during the past year (p=0.064) and BMI (p=0.247) showed no significant association. Furthermore, mean CAT score differed neither between men and women (p=0.320), nor across smoking status (yes, no, more, never) (p=0.280).

Table 3: Correlations of steps, PA₃, PAL and 6MWD with CAT score

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily steps ¹</td>
<td>-0.37</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average daily PA₃ [min]¹</td>
<td>-0.25</td>
<td>0.014</td>
</tr>
<tr>
<td>Average daily PAL [METs]¹</td>
<td>-0.18</td>
<td>0.058</td>
</tr>
<tr>
<td>6MWD [m]²</td>
<td>-0.33</td>
<td>0.002</td>
</tr>
</tbody>
</table>

CAT, COPD assessment test; METs, metabolic equivalents of task; PAL, physical activity level; PA₃, physical activity duration above 3 METs; r, correlation coefficient; 6MWD, 6-minute walk distance. Significant p-values are highlighted in bold. ¹ (n=78); ² (n=83).

2.4.3 Independent predictors of quality of life

The multiple linear regression analysis with CAT score as dependent variable is presented in Table 4. R² of the analysis was 0.31. Average daily steps, 6MWD and age contributed significantly to the model. In contrast, PA₃ and FEV₁%predicted were not found to have a significant impact on CAT score. The correlations between CAT score and the variables average daily steps and 6MWD are shown in Figures 2 and 3.
Table 4: Forced entry multiple linear regression analysis with CAT score as dependent variable

<table>
<thead>
<tr>
<th>Model: n=78, ( R^2=0.31 )</th>
<th>( B )</th>
<th>( SE \ B )</th>
<th>( \beta )</th>
<th>( p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>44.84</td>
<td>7.33</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>-0.27</td>
<td>0.08</td>
<td>-0.39</td>
<td>0.001</td>
</tr>
<tr>
<td>6MWD [m]</td>
<td>-0.02</td>
<td>0.01</td>
<td>-0.32</td>
<td>0.019</td>
</tr>
<tr>
<td>Average daily steps</td>
<td>-0.00</td>
<td>0.01</td>
<td>-0.31</td>
<td>0.033</td>
</tr>
<tr>
<td>FEV(_1) predicted [%]</td>
<td>-0.03</td>
<td>0.03</td>
<td>-0.10</td>
<td>0.364</td>
</tr>
<tr>
<td>Average daily PA(_3) [min]</td>
<td>0.01</td>
<td>0.01</td>
<td>0.08</td>
<td>0.498</td>
</tr>
</tbody>
</table>

\( B \), unstandardized regression coefficient; \( \beta \), standardized beta coefficient; CAT, COPD assessment test; FEV\(_1\) predicted, forced expiratory volume in one second of predicted; PA\(_3\), physical activity duration above 3 METs; SE, standard error; 6MWD, 6-minute walk distance. Significant \( p\)-values are highlighted in bold.

2.4.4 Independent predictors of functional capacity

The multiple linear regression analysis with 6MWD as dependent variable is presented in Supplemental file 1. \( R^2 \) of the analysis was 0.53. Age, daily steps and CAT score were found to contribute significantly to the model, whereas PA\(_3\) showed no significant association with 6MWD.

![Figure 2: Correlation between CAT score and average daily steps (n=78, r=-0.37, p<0.001, y=17.761-0.001*x). CAT, COPD assessment test.](image-url)
Figure 3: Correlation between CAT score and 6MWD (n=83, r=-0.33, p=0.002, y=22.371-0.022*x).

CAT, COPD assessment test; 6MWD, 6-minute walk distance.

Supplemental file 1: Forced entry multiple linear regression with 6MWD as dependent variable

<table>
<thead>
<tr>
<th>Model: n=78, R²=0.53</th>
<th>B</th>
<th>SE B</th>
<th>ß</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>749.84</td>
<td>7.99</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>-4.91</td>
<td>0.98</td>
<td>-0.45</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average daily steps</td>
<td>0.01</td>
<td>0.00</td>
<td>0.37</td>
<td>0.002</td>
</tr>
<tr>
<td>CAT score</td>
<td>-3.70</td>
<td>1.42</td>
<td>-0.24</td>
<td>0.011</td>
</tr>
<tr>
<td>Average daily PA₃ [min]</td>
<td>0.01</td>
<td>0.13</td>
<td>0.01</td>
<td>0.945</td>
</tr>
</tbody>
</table>

B, unstandardized regression coefficient; ß, standardized beta coefficient; CAT, COPD assessment test; PA₃, physical activity duration above 3 METs; SE, standard error; 6MWD, 6-minute walk distance. Significant p-values are highlighted in bold.
2.5 Discussion

The main findings of this study were that average daily steps, 6MWD and age showed an independent association with HRQOL measured by CAT, whereas PA₃ and FEV₁%predicted did not influence CAT score.

Regarding previous studies, Moy et al. [25] found as well that average daily steps were significantly associated with HRQOL, when measured by an accelerometer. Furthermore, time spent in mild-to-moderate physical activity and mobility were found to be reduced in patients with COPD compared to their healthy counterparts [26, 27]. Although in the present study PA₃ as a measure of moderate-to-high intensity physical activity was not found to be independently associated with HRQOL, Jehn et al. [28] identified daily walking intensity as a predictor of HRQOL. However, they defined intensity by “fast walk” >5 km/h, which is not directly comparable to PA₃ expressing the time spent active above 3 METs.

Furthermore, our results confirmed previous studies, which found a significant association between functional capacity and HRQOL [3, 7, 9]. However, this is the first study that identified 6MWD as an independent predictor of CAT score. In contrast, a recently published study found no significant correlation between 6MWD and CAT score after pulmonary rehabilitation [29]. However, the two study samples might not be directly comparable, because most of their patients were in GOLD grades II (48%) and III (25%), whereas the majority of our patients was in GOLD grades I (26%) and II (53%). It could be implied that functional capacity measured by 6MWT and HRQOL assessed by CAT might be related only in less severe grades.

In addition, an inverse correlation between age and HRQOL was found, meaning that older patients had a better HRQOL. This relationship was also seen in previous studies [7, 28]. Based on conversations with the patients, it could be possible that younger patients with COPD feel more impaired by their disease than elders. For example, older individuals might be satisfied with walking at slow pace, whereas younger patients may find this limiting, because their peers walk faster. Another reason could be related to the time of diagnosis of COPD. Patients suffering from the disease for a long time might feel less impaired, because they may have adapted to the disease and accepted it as part of their life. However, this is only hypothetical and should be investigated by future studies.

In this study, FEV₁%predicted was not independently associated with HRQOL. This finding was similar to previous studies, which found no or just a weak correlation between FEV₁%predicted and HRQOL [7, 30-33]. Probably, FEV₁%predicted represents only a small part of the overall influence on HRQOL and might therefore not be adequate to independently determine HRQOL.

2.5.1 Clinical implications

For a better HRQOL, it may be advantageous for patients with COPD to maintain daily physical activity as an integral part of everyday life and to remain mobile, as for example walking to work, going shopping and meeting friends on foot.

2.5.2 Strengths and limitations

A strength of the present study was the use of CAT, a short instrument to measure HRQOL, which was easy to administer and could be completed more quickly than complex HRQOL questionnaires. This advantage might facilitate its use in routine clinical practice. Another strength was the assessment of daily physical activity by the SWMA. The combination of multiple sensors enables the SWMA to overcome limitations of conventional devices, such as pedometers and accelerometers. By measuring
heat produced by the body, the armband can detect energy expenditure associated with load carrying and free-living physical activity [18]. Furthermore, the integration of a three-axis accelerometer allows a more sensitive activity detection than a two-axis accelerometer [18].

However, the SWMA was found to underestimate the number of average daily steps at slow walking speeds in patients with COPD [34]. The present study still found a significant association between average daily steps and HRQOL assessed by CAT, which needs to be confirmed by further investigations. Because of limited resources, 6MWT was performed only once in this study, even though two tests are recommended according to current guidelines [12]. Hernandes et al. [35] found that the learning effect between the first and second test resulted in an increase in 6MWD of 27 meters. Another limitation was that only 31% of the variance in CAT score was explained by the regression model. This could be a consequence of the absence of other predictor variables in the model due to the limited sample size. Furthermore, the associations between CAT score and the included predictors were rather weak, but significant. The cross-sectional study design was also a limitation of this study, which does not allow statements about causality. To determine the direction of causality, a longitudinal intervention study with a larger sample size is required. Moreover, since most patients with COPD were in mild and moderate GOLD grades, the present study was not representative for severe GOLD grades. Patients in severe and very severe grades were often impaired in their mobility and therefore not willing to participate in this study.

2.5.3 Conclusions

The key finding of this cross-sectional investigation was that average daily steps and functional capacity as measured by 6MWT were independently associated with HRQOL assessed by CAT in patients with COPD. Our results may be beneficial for the development of adequate intervention strategies involving exercise and suggest the need for patients with COPD to maintain an active lifestyle.

2.5.4 Acknowledgements

We would like to express our gratitude to the foundations ‘Gottfried und Julia Bangerter-Rhyner-Stiftung’, ‘Freiwillige Akademische Gesellschaft Basel’ and ‘Forschungsfonds der Universität Basel’ for their financial support. In addition, we show appreciation to all 87 COPD patients for their participation in the present investigation.

2.5.5 Conflicts of Interest

The authors of the present study declare that they have no conflicts of interest.

2.5.6 Notice of publication

This manuscript was accepted as an Original Article and published by Informa Healthcare, now Taylor & Francis Group (Copyright © Informa Healthcare USA, Inc.) in COPD on 19/06/14. Available online: http://www.tandfonline.com/doi/full/10.3109/15412555.2014.898050.
2.6 References


Part II

Chapter 3: Association of occupational and leisure-time physical activity with aerobic capacity in a working population


3.1 Abstract

Introduction: The objective of this study was to analyse the association of maximal aerobic capacity (VO\textsubscript{2max}) with work and non-work related physical activity in a Swiss working population.

Methods: In this cross-sectional study, a total of 337 healthy and at least 80% employed adult workers were recruited. Demographic data, height, weight and body mass index were recorded in all subjects. Energy expenditure and physical activity were measured by the SenseWear Mini armband for seven consecutive days (23 hours/day). VO\textsubscript{2max} was evaluated using the multistage 20-meter shuttle run test.

Results: Data of 303 participants were considered for analysis (63% male, mean age: 33 yrs, SD 12, range: 18-61 yrs). Multiple linear regression analysis (adjusted R\textsuperscript{2}=0.70) with VO\textsubscript{2max} as dependent variable showed significant positive associations of VO\textsubscript{2max} with leisure-time physical activity at high intensity (β=0.11, p=0.007) and with active energy expenditure (β=0.12, p=0.009), but not with occupational physical activity at any intensity. Female gender (β=-0.56, p<0.001), age (β=-0.27, p<0.001), body mass index (β=-0.27, p<0.001), smoking (β=-0.13, p<0.001) and the ratio of maximal to resting heart rate (β=0.18, p<0.001) were also identified as independent predictors of VO\textsubscript{2max}. On workdays, VO\textsubscript{2max} was significantly higher in participants, who fulfilled the global recommendations on physical activity compared to insufficiently active counterparts.

Conclusions: The present results suggest that VO\textsubscript{2max} was positively associated with leisure-time physical activity, but not with occupational physical activity on workdays. This finding emphasises the need for employees to engage in sufficient high-intensity physical activity in recreation for maintaining or improving VO\textsubscript{2max} with regard to health benefits.

3.2 Introduction

VO\textsubscript{2max} is defined as the maximal rate of oxygen uptake. It is generally accepted as the most valid and reliable index of cardiorespiratory fitness and aerobic capacity [1]. Previous studies found that poor cardiorespiratory fitness was a risk factor for various diseases, such as hypertension, stroke, type 2 diabetes and metabolic syndrome [2, 3]. Other studies reported that a low VO\textsubscript{2max} was associated with all-cause mortality and mortality from cardiovascular disease [4].

VO\textsubscript{2max} is determined by genetic factors, age, gender as well as physical activity, body fat, smoking and medical conditions [5]. VO\textsubscript{2max} decreases with age with an average rate of decline of about 1% per year or 10% per decade after the age of 25 [6, 7]. Recent data suggest that the ability of an individual to increase VO\textsubscript{2max} is genetically determined. Each individual disposess of a predetermined genetic window, and can vary the amount of VO\textsubscript{2max} with exercise training or detraining within that window [8]. VO\textsubscript{2max} values range from about 10 ml/kg/min in severely ill cardiac patients to 80-90 ml/kg/min in world-class runners and cross-country skiers [9]. VO\textsubscript{2max} may be substantially increased in response to endurance training [8].
For decades, governmental and non-governmental agencies have promoted physical activity for individuals’ health benefits. The World Health Organization recommends that adults between 18 and 64 years should engage in ≥30 minutes of at least moderate-intensity physical activity on most days of the week. Aerobic activity should be performed in bouts of ≥10 minutes duration across different domains such as work, leisure-time, transport, domestic and garden [10]. Since most people in full-time employment spend one third or more of the day at work, it is conceivable that occupational physical activity (OPA) may contribute to a large extent to total daily activity. While leisure-time physical activity (LTPA) is well known to be positively associated with VO2max, only few data are available on the relationship between OPA and VO2max in employees. With regards to LTPA, Ong & Sothy [11] found that regularly exercising men in sedentary occupations had a significantly higher mean VO2max than non-regularly exercising counterparts. In contrast, the potential positive effects of OPA on VO2max are less well investigated [1]. However, available data suggest that OPA, independent of formal exercise programs, may positively affect VO2max [12].

Previous studies measuring physical activity in employees used pedometers and accelerometers in combination with self-report questionnaires. Self-report questionnaires are the most used method for physical activity assessment [13]. However, validation studies comparing self-report estimates to the gold standard method doubly-labeled-water (DLW) are inconsistent [14, 15]. Due to accuracy, ability to capture large amounts of data and ease of administration, accelerometers are widely used today [16]. However, they are not accurate in estimating physical activity during graded walking or load carrying [17]. Pedometers directly observe time spent in physical activities, but do not record intensity and frequency of physical activity or purely upper body movements [18]. Armband devices, such as the SenseWear Mini armband (SWMA), integrate motion and heat-related sensors. This dual measurement strategy is more sensitive for assessing energy expenditure associated with complex and non-ambulatory activities, such as carrying a load while walking [19]. Furthermore, this method ensures a sensitive determination of acceleration provoked by muscle power or externally by a vehicle or gravitation [19].

Due to methodological limitations and lack of studies, potential associations of objectively measured physical activity and VO2max in employees still need to be clarified by further investigations. Therefore, the primary aim of this study was to analyse the relationship between VO2max and work and non-work related physical activity as measured by the SWMA in a Swiss working population. The secondary objective was to evaluate the effect of demographic factors on VO2max including gender, age, body mass index (BMI) and smoking.

3.3 Materials and Methods

3.3.1 Study participants

From May 17, 2013 (first participant in) to February 11, 2015 (last participant in), a total of 337 healthy and at minimum 80% employed adult workers from various companies of the Basel region, Switzerland were recruited. Exclusion criteria were insufficient knowledge of the German language, movement restrictions as well as diseases and accidents within the last three months that affected productivity at the workplace. Furthermore, night shift workers could not take part in this study because of their altered sleep, eating and physical activity behaviour. This investigation has been conducted according to the Declaration of Helsinki and was approved by the local ethics committee “Ethikkommission Nordwest- und Zentralschweiz” (EKNZ, 260/12) on December 21, 2012. Written informed consent was obtained from all study participants prior to study entry.
3.3.2 Study design and procedures

In this cross-sectional study, the aim was to recruit an equal distribution of subjects across different occupational groups. A permit from leading persons of miscellaneous companies was requested to receive contact details for potentially recruitable employees, who were then informed and asked for study participation by phone or by email. The selected companies included medium sized corporations from the public sector (e.g. hospitals) as well as small sized private firms (e.g. construction companies). At the first study visit, height and weight were reliably measured. Height was assessed without shoes by a medical measuring stick to the nearest mm (model Seca 217, measurement range: 20 to 205 cm, Seca AG, Reinach, Switzerland). The measurement of weight was performed on subjects in light clothing without shoes by a medical scale with an accuracy of 0.1 kg (model Seca 877, load capacity: 200 kg, Seca AG, Reinach, Switzerland). BMI was calculated from measured height and weight (BMI = weight/height$^2$ [kg/m$^2$]). Subjects with a BMI of 25 kg/m$^2$ or more were classified as overweight, and those with a BMI of 30 kg/m$^2$ or more as obese [20]. In addition, a variety of personal and job-related factors were recorded by a generic questionnaire, such as age, gender, nationality, marital status, smoking status, alcohol consumption, highest education, current profession, daily working hours, working time model, medication, psychotherapy, illnesses and accidents within the last three months. The reported professions were classified into nine categories based on the International Standard Classification of Occupations 1988 (ISCO-88) [21]. Participants were then merged into three groups with low, moderate and high OPA [22]. Prior to the observation period, subjects performed a 20-meter shuttle run test in order to determine VO$_{2\text{max}}$. During the subsequent week, participants were instructed to wear the SWMA on seven consecutive days in order to objectively measure daily physical activity. One week later at the second study visit, all subjects completed the self-administered International Physical Activity Questionnaire (IPAQ).

3.3.3 Measurements

20-meter shuttle run test

The multistage 20-meter shuttle run test is a common endurance fitness test to evaluate the maximal aerobic capacity of healthy adults. It is simple in use, economical and large groups can be tested simultaneously. Validity of the one-minute stage version of the 20-meter shuttle run to predict VO$_{2\text{max}}$ in adults was established by Léger & Gadoury [23], who compared the maximal shuttle run speed to VO$_{2\text{max}}$ attained during a multistage treadmill test (r=0.90). Test-retest reliability was found to be very high in healthy adults (r=0.95) [23]. This test was conducted on a flat, non-slip surface. Participants were instructed to run back and forth between two lines, which were 20 meters apart, with a running velocity determined by audio signals [23]. Starting speed was 8.5 km/h and every minute (stage), speed was increased by 0.5 km/h until the subject could no longer keep the pace and did not reach the lines in time twice in a row [23]. The test result corresponded to the number of reached stages and shuttles. According to a validated table [24], this score was used to predict VO$_{2\text{max}}$, which could be compared to age-dependent normative data for males and females. In addition, resting heart rate (HR$_{\text{rest}}$) was assessed prior to testing, heart rate was continuously recorded during the test up to maximal frequency (HR$_{\text{max}}$) and recovery pulse (HR$_{\text{recovery}}$) was measured two minutes after the end of the test. The ratios of HR$_{\text{max}}$/HR$_{\text{rest}}$, HR$_{\text{max}}$/HR$_{\text{recovery}}$ were calculated as (HR$_{\text{max}}$/HR$_{\text{rest}}$) and (HR$_{\text{max}}$/HR$_{\text{recovery}}$) [25], respectively. Four participants did not perform the 20-meter shuttle run due to a resting systolic blood pressure >180 mmHg. They were pairwise excluded from the corresponding analyses.
**SenseWear Mini armband**

The SWMA (model MF-SW) is a small, lightweight and wireless multisensory activity monitor developed by BodyMedia Inc., Pittsburgh, Pennsylvania, USA (now Jawbone Inc., San Francisco, California, USA), which integrates motion data from a three-axis accelerometer along with other sensors such as heat flux, skin temperature and galvanic skin response. Validity of the SWMA was established by Johannsen *et al.* [19] comparing energy expenditure estimates of the SWMA against the criterion method DLW in healthy adults ($r=0.87$).

Subjects were instructed to wear the SWMA on the upper left arm (triceps area) for seven consecutive days, including while sleeping, with the exception of the time spent on personal hygiene. The first and the last incomplete measurement day, including the study visits, were not taken into account. Therefore, the investigated measurement period was five days, which had to consist of at least three workdays to be included in the analysis [26]. A day was considered as a whole workday, if participants worked cumulatively ≥6 hours, and as a half workday in case of ≥3 to <6 hours. Days with <3 working hours were regarded as non-work days. Measurement periods of <22 hours per day or <12 hours during wake-time were excluded from analysis [27]. Information about workdays and non-work days as well as work-time and leisure-time on workdays was obtained from diaries participants filled in during the measurement period.

**International Physical Activity Questionnaire**

The IPAQ represents a simple instrument for measuring health-enhancing physical activity at the population level. Validity and reliability were established in 12 different countries [28]. The self-administered German long version of the IPAQ designed for adults aged 15 to 69 years was filled in by the participants. It includes 26 questions and assesses past-week frequency and duration of physical activity within the domains of work, leisure-time, transport, domestic and garden. Moreover, each domain consists of walking, moderate and vigorous activities.

3.3.4 Calculation of physical activity scores

The physiological data, collected by the armband’s sensors, were processed by specific algorithms available in the SWMA software (BodyMedia, professional software V.7.0, algorithm V.2.2.4). Patients’ average daily number of steps, activity-related energy expenditure (AEE), physical activity level in metabolic equivalents of task (METs) and physical activity duration at different intensities were examined. One MET corresponds to 3.5 ml O$_2$/min/kg [29]. For all variables, average values were calculated separately for workdays and non-work days as well as for work-time and leisure-time on workdays. The amount of physical activity (min/day) at a certain intensity level was calculated in two ways. First, one-minute intervals in which the intensity reached the following MET thresholds were summed up: moderate physical activity (MPA) ≥3 to <6 METs, high physical activity (HPA) ≥6 to <9 METs and very high physical activity (VHPA) ≥9 METs. Second, because current guidelines suggest accumulating physical activity bouts of ≥10 minutes [29], this was considered in the calculation of moderate-to-vigorous physical activity (MVPA) ≥3 METs. Thus, we were able to investigate whether participants fulfilled the recommendation of MVPA of ≥30 minutes per day calculated from bouts of ≥10 minutes on workdays and non-work days [30].
In order to compare objective SWMA data with subjective IPAQ data, daily means of MPA and HPA (min/day) were calculated for work and total recreation. For the SWMA, mean values of leisure-time on workdays and non-work days were summed up and divided by the number of analysed days. For the IPAQ, MPA during work was determined by the sum of walking (3.3 METs) and moderate (4 METs) activity minutes. Regarding recreation, walking and moderate activity minutes from the domains of leisure-time, transport, domestic and garden were added up. To compute HPA for work and recreation, high (8 METs) activity minutes were considered within the corresponding domain.

3.3.5 Statistical analysis

Data were analysed using IBM SPSS Statistics (version 22.0). Significance was set at the 5% level. The Shapiro-Wilk test was used to test whether data were normally distributed. Data are presented as mean and standard deviation (SD) or number and percentage. To analyse differences across gender and physical activity categories, mean comparisons were performed using Student-T test or Mann-Whitney test, if appropriate. Categorical data were analysed with Chi-Square test. To identify potential predictors of VO$_{2\max}$, multiple linear regression analyses were performed using the backward stepwise method. AEE measured by the SWMA was subject to power calculation. Assuming a sample size of 100 subjects in each occupational group, there is a power of >90% to detect a mean difference of 500 kcal between any of these groups. This calculation was based on the assumption of a within group SD of 730 kcal and on a two-sided significance level of 5% [31].

3.4 Results

3.4.1 Subjects' characteristics

Of the 337 recruited subjects 303 were considered for analysis. Descriptive data for total (n=303), male (n=190, 63%) and female (n=113, 37%) subjects are presented in Table 1. 31% of subjects (n=95) were found to be overweight and 7% (n=21) were obese. Age ranged from 18 to 61 years and did not differ significantly between sexes. A higher percentage of males compared to females were current smokers, while more women than men were ex-smokers. BMI, HR$_{\text{max}}$ and HR$_{\text{recovery}}$ were significantly increased in male subjects. In contrast, only HR$_{\text{rest}}$ was higher in females. Gender distribution was more or less balanced in group 1 (low OPA) and group 2 (moderate OPA), while only 4% of the investigated females were represented in group 3 (high OPA).

Thirty-four subjects (10%) have worn the SWMA on less than three workdays and were therefore excluded from the entire analysis. Reasons for non-wearing or non-evaluation were: technical problems (n=4), illness during observation period (n=2), no paid occupation (n=5), no interest (n=15), loss of the armband (n=4), skin irritations (n=2) or sleep problems (n=2). Another 24 individuals had missing SWMA data on non-work days due to more workdays during observation period and were pairwise excluded from the corresponding analyses.
Table 1: Characteristics of study subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=303)</th>
<th>Male (n=190)</th>
<th>Female (n=113)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N (%)/ Mean (SD)</strong></td>
<td><strong>N (%)/ Mean (SD)</strong></td>
<td><strong>N (%)/ Mean (SD)</strong></td>
<td><strong>N (%)/ Mean (SD)</strong></td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>33 (12)</td>
<td>33 (13)</td>
<td>35 (12)</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>24 (3)</td>
<td>25 (3) ***</td>
<td>23 (4)</td>
</tr>
<tr>
<td>Current smokers</td>
<td>64 (21)</td>
<td>46 (24)</td>
<td>18 (16)</td>
</tr>
<tr>
<td>Ex-smokers</td>
<td>61 (20)</td>
<td>32 (17)</td>
<td>28 (25)</td>
</tr>
<tr>
<td>HRrest</td>
<td>72 (13)</td>
<td>70 (13)*</td>
<td>74 (13)</td>
</tr>
<tr>
<td>HRmax</td>
<td>183 (15)</td>
<td>187 (14) ***</td>
<td>178 (15)</td>
</tr>
<tr>
<td>HRrecovery</td>
<td>106 (15)</td>
<td>108 (14) **</td>
<td>102 (16)</td>
</tr>
<tr>
<td>Group 1 (low OPA)</td>
<td>101 (33)</td>
<td>55 (29)</td>
<td>46 (41)</td>
</tr>
<tr>
<td>Group 2 (moderate OPA)</td>
<td>102 (34)</td>
<td>40 (21)</td>
<td>62 (55)</td>
</tr>
<tr>
<td>Group 3 (high OPA)</td>
<td>100 (33)</td>
<td>95 (50) **</td>
<td>5 (4)</td>
</tr>
</tbody>
</table>

BMI, body mass index; HRmax, maximal heart rate; HRrecovery, recovery pulse (measured two minutes after the end of the 20-meter shuttle run test); HRrest, resting heart rate; OPA, occupational physical activity; SD, standard deviation; VO₂max, maximal oxygen uptake during 20-meter shuttle run test. *p<0.05, **p<0.01, ***p<0.001 (two-tailed) vs. females.

3.4.2 Physical activity data

Table 2 illustrates VO₂max and objective physical activity measured by the SWMA according to gender. Males had a significantly higher VO₂max than females. Overall, most physical activity was performed within the moderate-intensity range. Furthermore, activity levels at all intensities, AEE and the number of daily steps were higher in males compared to females. Activity parameters differed significantly between sexes on workdays during work- and leisure-time (with the exception of VHPA during leisure-time), while no gender-dependent differences in physical activity were found on non-work days (except AEE). Moreover, men showed higher physical activity levels on workdays (work-time and leisure-time added) than on non-work days. In women, this was the case for MPA, AEE and steps, whereas it was the contrary for HPA and VHPA.

Subjective activity data assessed by the IPAQ compared to objective data measured by the SWMA are presented in Figure 1, according to gender. In total subjects, MPA at work was underreported by two-thirds using the IPAQ compared to the SWMA (51 min/day, SD 73 vs. 151 min/day, SD 131), while MPA in recreation was underreported by approximately 50% (58 min/day, SD 48 vs. 130 min/day, SD 59). In contrast, HPA at work was overreported by almost 100% (14 min/day, SD 36 vs. 8 min/day, SD 14) and in recreation by approximately two-thirds (16 min/day, SD 21 vs. 10 min/day, SD 11) with the IPAQ compared to the SWMA.
Table 2: Physical activity data, measured with objective methodology, SenseWear Mini armband

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=303)</th>
<th>Male (n=190)</th>
<th>Female (n=113)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO\textsubscript{2max} [ml/kg/min]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>40 (10)</td>
<td>45 (8) ***</td>
<td>33 (7)</td>
</tr>
<tr>
<td>Male</td>
<td>151 (131)</td>
<td>190 (143) ***</td>
<td>85 (70)</td>
</tr>
<tr>
<td>Female</td>
<td>107 (50)</td>
<td>113 (52) *</td>
<td>98 (44)</td>
</tr>
<tr>
<td>Work-time</td>
<td>178 (105)</td>
<td>187 (110)</td>
<td>164 (94)</td>
</tr>
<tr>
<td>Leisure-time</td>
<td>8 (14)</td>
<td>11 (16) ***</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Non-work day</td>
<td>9 (11)</td>
<td>10 (11) **</td>
<td>7 (11)</td>
</tr>
<tr>
<td>Non-work day</td>
<td>12 (18)</td>
<td>13 (21)</td>
<td>9 (13)</td>
</tr>
<tr>
<td><strong>MPA [min/day]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work-time</td>
<td>0.2 (1.3)</td>
<td>0.3 (1.6) **</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Leisure-time</td>
<td>1.9 (4.8)</td>
<td>2.2 (5.4)</td>
<td>1.4 (3.6)</td>
</tr>
<tr>
<td>Non-work day</td>
<td>2.1 (7.4)</td>
<td>2.0 (8.2)</td>
<td>2.3 (6.0)</td>
</tr>
<tr>
<td><strong>HPA [min/day]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work-time</td>
<td>795 (816)</td>
<td>1068 (905) ***</td>
<td>337 (273)</td>
</tr>
<tr>
<td>Leisure-time</td>
<td>609 (321)</td>
<td>700 (341) ***</td>
<td>456 (211)</td>
</tr>
<tr>
<td>Non-work day</td>
<td>950 (632)</td>
<td>1089 (706) ***</td>
<td>724 (398)</td>
</tr>
<tr>
<td><strong>VHPA [min/day]</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work-time</td>
<td>6521 (3888)</td>
<td>7511 (4292) ***</td>
<td>4855 (2285)</td>
</tr>
<tr>
<td>Leisure-time</td>
<td>5638 (2592)</td>
<td>5470 (2727) *</td>
<td>5919 (2332)</td>
</tr>
<tr>
<td>Non-work day</td>
<td>8997 (6190)</td>
<td>9187 (7321)</td>
<td>8685 (3673)</td>
</tr>
</tbody>
</table>

AEE, activity-related energy expenditure; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SD, standard deviation; VO\textsubscript{2max}, maximal oxygen uptake during 20-meter shuttle run test. *p<0.05, **p<0.01, ***p<0.001 (two-tailed) vs. females.

3.4.3 VO\textsubscript{2max} across categories of physical activity

On workdays, VO\textsubscript{2max} was significantly higher in participants (42 ml/kg/min, SD 9), who were sufficiently active (≥30 minutes MVPA/day, n=251, 84%) compared to those (31 ml/kg/min, SD 7), who were insufficiently active (<30 minutes MVPA/day, n=48, 16%) (p<0.01). However, on non-work days, the difference between sufficiently (n=208, 75%) and insufficiently (n=71, 25%) active participants was not significant (41 ml/kg/min, SD 9 vs. 37 ml/kg/min, SD 10, p=0.129).

Regarding the combination of physical activity categories on workdays and non-work days, VO\textsubscript{2max} was found to be lowest in the category, which did not fulfil the activity recommendations on both workdays and non-work days (30 ml/kg/min), slightly increased in the category, which fulfilled the recommendations on non-work days, but not on workdays (34 ml/kg/min), clearly higher in those, who were sufficiently active on workdays, but not on non-work days (41 ml/kg/min) and highest in the category, which fulfilled the recommendations on both workdays and non-work days (42 ml/kg/min).

3.4.4 VO\textsubscript{2max} reference values

Average VO\textsubscript{2max} values stratified for age and gender are given in Table 3. They were found to be well within the representative reference ranges of VO\textsubscript{2max} for non-athletes provided by Wilmore & Costill [8].
Figure 1: Comparison of objective activity data measured by the SenseWear Mini armband (SW) with subjective activity data assessed by the International Physical Activity Questionnaire (IPAQ).

HPA_Work_IPAQ / HPA_Recreation_IPAQ, physical activity at high intensity (8 METs) assessed by the International Physical Activity Questionnaire; HPA_Work_SW / HPA_Recreation_SW, physical activity at high intensity (6-9 METs) measured by the SenseWear Mini armband; MPA_Work_IPAQ / MPA_Recreation_IPAQ, physical activity at moderate intensity (3 METs: inside chores, 3.3 METs: walking, 4 METs: moderate activity at work, yard work or in leisure-time, 5.5 METs: vigorous yard chores, 6 METs: cycle for transport) assessed by the International Physical Activity Questionnaire; MPA_Work_SW / MPA_Recreation_SW, physical activity at moderate intensity (3-6 METs) measured by the SenseWear Mini armband.
Table 3: \( \text{VO}_2\text{max} \) reference values according to age and gender

<table>
<thead>
<tr>
<th>Age category</th>
<th>N (%)</th>
<th>Mean (SD)</th>
<th>Decrease over decade</th>
<th>( \text{VO}_2\text{max} ) [ml/kg/min] ranges for non-athletes according to Wilmore &amp; Costill [8]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total:</td>
<td>303</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-29 yrs</td>
<td>131 (43)</td>
<td>43 (9)</td>
<td>- 5%</td>
<td>48 (43-52)</td>
</tr>
<tr>
<td>30-39 yrs</td>
<td>77 (26)</td>
<td>41 (9)</td>
<td></td>
<td>44 (39-48)</td>
</tr>
<tr>
<td>40-49 yrs</td>
<td>52 (17)</td>
<td>39 (8)</td>
<td>- 5%</td>
<td>40 (36-44)</td>
</tr>
<tr>
<td>50-61 yrs</td>
<td>43 (14)</td>
<td>33 (8)</td>
<td>- 15%</td>
<td></td>
</tr>
<tr>
<td>Males:</td>
<td>190</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-29 yrs</td>
<td>91 (48)</td>
<td>47 (7)</td>
<td>- 4%</td>
<td>44 (39-48)</td>
</tr>
<tr>
<td>30-39 yrs</td>
<td>40 (21)</td>
<td>45 (9)</td>
<td></td>
<td>40 (36-44)</td>
</tr>
<tr>
<td>40-49 yrs</td>
<td>36 (19)</td>
<td>42 (7)</td>
<td>- 7%</td>
<td></td>
</tr>
<tr>
<td>50-61 yrs</td>
<td>23 (12)</td>
<td>38 (6)</td>
<td>- 10%</td>
<td>38 (34-41)</td>
</tr>
<tr>
<td>Females:</td>
<td>113</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-29 yrs</td>
<td>40 (35)</td>
<td>34 (7)</td>
<td>+ 6%</td>
<td>38 (33-42)</td>
</tr>
<tr>
<td>30-39 yrs</td>
<td>37 (33)</td>
<td>36 (6)</td>
<td></td>
<td>34 (30-38)</td>
</tr>
<tr>
<td>40-49 yrs</td>
<td>16 (14)</td>
<td>31 (5)</td>
<td>- 14%</td>
<td>31 (26-35)</td>
</tr>
<tr>
<td>50-61 yrs</td>
<td>20 (18)</td>
<td>26 (4)</td>
<td>- 16 %</td>
<td>29 (24-33)</td>
</tr>
</tbody>
</table>

SD, standard deviation; \( \text{VO}_2\text{max} \), maximal oxygen uptake during 20-meter shuttle run test.

3.4.5 Independent predictors of \( \text{VO}_2\text{max} \)

Results of the backward stepwise multiple linear regression analyses with \( \text{VO}_2\text{max} \) as dependent variable are presented in Table 4. Adjusted \( R^2 \) of model 1 including objective SWMA activity parameters was 0.70. In decreasing order, female gender, age, BMI, \( \text{HR}_{\text{max}} \)-to-\( \text{HR}_{\text{rest}} \), smoking, MPA during work-time, AEE and HPA in leisure-time, as well as VHPA on non-work days contributed significantly to the model. In contrast, AEE, HPA, VHPA and steps during work-time, MPA and steps in leisure-time, AEE, MPA, HPA and steps on non-work days, ex-smoking and \( \text{HR}_{\text{max}} \)-to-\( \text{HR}_{\text{recovery}} \) were not found to be significant predictors of \( \text{VO}_2\text{max} \). Based on the results of multiple linear regressions, this study has generated the following prediction equation for model 1:

\[
\text{VO}_2\text{max} \, [\text{ml/kg/min}] = 72.595 - (11.454 \times \text{Gender}; \text{Men} = 0, \text{Women} = 1) - (0.203 \times \text{Age [yrs]}) - (0.724 \times \text{BMI [kg/m}^2]) + (3.614 \times \text{HR}_{\text{max}} \text{-to-}\text{HR}_{\text{rest}}) - (3.040 \times \text{Current smokers; Never smokers} = 0, \text{Current smokers} = 1) + (0.004 \times \text{AEE leisure-time [kcal/day]}) - (0.008 \times \text{MPA work-time [min/day]}) + (0.095 \times \text{HPA leisure-time [min/day]}) + (0.107 \times \text{VHPA non-work day [min/day]}).
\]

Model 2 included subjective activity parameters of the IPAQ. Adjusted \( R^2 \) of the analysis was 0.66 and thus only slightly lower than computed with the objective SWMA activity data. Age, female gender, BMI, smoking, \( \text{HR}_{\text{max}} \text{-to-}\text{HR}_{\text{rest}}, \text{HR}_{\text{max}} \text{-to-}\text{HR}_{\text{recovery}} \) and HPA in recreation contributed significantly to the model. In contrast, ex-smoking, MPA from both work and recreation as well as HPA at work were not found to be significant predictors of \( \text{VO}_2\text{max} \).
Table 4: Backward stepwise multiple linear regression analyses with VO$_{2\text{max}}$ as dependent variable

**Objective SenseWear Mini armband data**

<table>
<thead>
<tr>
<th>Model 1: n=273, Adjusted $R^2$=0.70</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>72.595</td>
<td>4.242</td>
<td>-0.599</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender (Male vs. Female)</td>
<td>-11.454</td>
<td>0.840</td>
<td>-0.599</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>-0.203</td>
<td>0.029</td>
<td>-0.271</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI [kg/m$^2$]</td>
<td>-0.724</td>
<td>0.107</td>
<td>-0.265</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HR$<em>{\text{max}}$-to-HR$</em>{\text{rest}}$</td>
<td>3.614</td>
<td>0.715</td>
<td>0.183</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Current smokers</td>
<td>-3.040</td>
<td>0.811</td>
<td>-0.132</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AEE leisure-time [kcal/day]</td>
<td>0.004</td>
<td>0.001</td>
<td>0.122</td>
<td>0.009</td>
</tr>
<tr>
<td>MPA work-time [min/day]</td>
<td>-0.008</td>
<td>0.003</td>
<td>-0.113</td>
<td>0.009</td>
</tr>
<tr>
<td>HPA leisure-time [min/day]</td>
<td>0.095</td>
<td>0.035</td>
<td>0.111</td>
<td>0.007</td>
</tr>
<tr>
<td>VHPA non-work day [min/day]</td>
<td>0.107</td>
<td>0.046</td>
<td>0.086</td>
<td>0.020</td>
</tr>
</tbody>
</table>

**Subjective International Physical Activity Questionnaire data**

<table>
<thead>
<tr>
<th>Model 2: n=303, Adjusted $R^2$=0.66</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>20.532</td>
<td>1.118</td>
<td>-0.640</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender (Male vs. Female)</td>
<td>-3.583</td>
<td>0.212</td>
<td>-0.289</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI [kg/m$^2$]</td>
<td>-0.228</td>
<td>0.029</td>
<td>-0.198</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>-0.043</td>
<td>0.008</td>
<td>-0.181</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HR$<em>{\text{max}}$-to-HR$</em>{\text{rest}}$</td>
<td>1.033</td>
<td>0.241</td>
<td>0.159</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HPA recreation [min/day]</td>
<td>0.020</td>
<td>0.004</td>
<td>0.091</td>
<td>0.027</td>
</tr>
<tr>
<td>Current smokers</td>
<td>-0.889</td>
<td>0.236</td>
<td>-0.134</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HR$<em>{\text{max}}$-to-HR$</em>{\text{recovery}}$</td>
<td>0.018</td>
<td>0.008</td>
<td>0.091</td>
<td>0.027</td>
</tr>
</tbody>
</table>

AEE, activity-related energy expenditure; B, unstandardized regression coefficient; $\beta$, standardized beta coefficient; BMI, body mass index; HR$_{\text{max}}$-to-HR$_{\text{rest}}$, ratio of maximal to resting heart rate; HR$_{\text{max}}$-to-HR$_{\text{recovery}}$, ratio of maximal to recovery heart rate; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SE, standard error; VO$_{2\text{max}}$, maximal oxygen uptake during 20-meter shuttle run test.

Model 1: Excluded variables were AEE, HPA, VHPA and Steps during work-time, MPA and Steps in leisure-time, AEE, MPA, HPA and Steps on non-work days, Ex-smokers, HR$_{\text{max}}$-to-HR$_{\text{rest}}$.

Model 2: Excluded variables were MPA and HPA at work, MPA in recreation, Ex-smokers.

### 3.5 Discussion

#### 3.5.1 Main findings

This cross-sectional study found that men had higher levels of both physical activity and VO$_{2\text{max}}$ than women. In general, physical activity was more common during workdays than during non-work days, especially among men. In addition, on workdays, mean VO$_{2\text{max}}$ was significantly higher in participants who fulfilled the global recommendations on physical activity compared to insufficiently active counterparts. Multiple linear regression analysis with VO$_{2\text{max}}$ as dependent variable showed significant positive associations of VO$_{2\text{max}}$ with LTPA at high intensities and with AEE, but not with OPA at any intensity (except negatively with MPA). Female gender, age, BMI, HR$_{\text{max}}$-to-HR$_{\text{rest}}$ and smoking were found to be additional independent predictors of VO$_{2\text{max}}$. Furthermore, a substantial discrepancy between objective SWMA and subjective IPAQ data was detected.
3.5.2 Predictors of VO\(_{2\text{max}}\)

The present results are in line with existing knowledge that females usually present lower levels of physical activity and VO\(_{2\text{max}}\). The regression model with objective SWMA data has shown that female gender is the strongest predictor of VO\(_{2\text{max}}\). The gender difference in VO\(_{2\text{max}}\) can partly be explained by women’s greater fat mass and lower hemoglobin levels compared to men, which result in a lower oxygen content in the arterial blood [8]. Furthermore, females have smaller muscle fiber cross-sectional areas and typically less muscle mass than males [8]. The decline of VO\(_{2\text{max}}\) with age in the present study is comparable to previous studies of Jackson et al. [6, 7]. In this study, participants younger than 50 years had a mean decline of <10% per decade and those older than 50 years a decline of >10% per decade. As shown by previous studies, measured VO\(_{2\text{max}}\) presented a significant negative association with BMI. The ratio of HR\(_{\text{max}}\)-to-HR\(_{\text{rest}}\) contributed positively to the model, which is in line with a study of well-trained men by Uth et al. [25], who observed highly significant correlations between measured VO\(_{2\text{max}}\) and the Heart Rate Ratio Method. Consistent with previous investigations, VO\(_{2\text{max}}\) was negatively associated with smoking [32]. In this study, only HPA and VHPA in recreation contributed significantly to the regression model and showed a positive association with VO\(_{2\text{max}}\). Wilmore & Costill [8] stated that the higher the initial state of fitness, the smaller is the relative improvement for the same volume of workdays. Concerning women, the present results were consistent with their decade and those older than 50 years a decline by VO\(_{2\text{max}}\). Jang et al. [1] suggested that OPA could have a significant effect on VO\(_{2\text{max}}\). Hirai et al. [34] also found a significant relationship between work form and VO\(_{2\text{max}}\) in male workers. The reason that they found positive associations between OPA and VO\(_{2\text{max}}\) might be that they used simple self-report questionnaires for assessing OPA. Miller & Brown [35] stated that measuring work-related activity is problematic, because the intermittent and unstructured nature of most work-related activities makes self-report difficult. The paradox that MPA during work-time showed a significant negative association with VO\(_{2\text{max}}\) could be explained by the lack of motivation to engage in high-intensity sports and exercises after a work-shift with a large proportion of MPA and the habit to spend time in activities that require no high physical exertion, as for example hard workers do at work.

3.5.3 Generalizability of results

The present study included a wide range of manual and non-manual employees and represented a typical cross-section of the Swiss working population. Mean BMI, percentage of overweight, obesity, as well as gender distribution were comparable to the Swiss working population in 2014 [36]. Furthermore, VO\(_{2\text{max}}\) values were in high agreement with a previous population-based study in US employees [37]. This applies to mean total VO\(_{2\text{max}}\) as well as mean VO\(_{2\text{max}}\) in men and women. Physical activity data measured by the SWMA were comparable to a recent study that objectively measured physical activity in 9554 Finnish employees with the Firstbeat Bodyguard device (beat-by-beat 24-hour heart rate and heart rate variability measurement) [38]. In both studies, most physical activity was performed within the moderate-intensity range, and activity levels at all intensities were higher in males compared to females. Contradictory to this study was that on non-work days men accumulated more physical activity at all intensities than on workdays. Concerning women, the present results were consistent with their
findings. In both studies, women showed more MPA on work days compared to non-work days, while it was the contrary for HPA and VHPA.

3.5.4 Findings in relation to physical activity recommendations
In this study, 84% and 75% of participants fulfilled the activity recommendations of ≥30 minutes MVPA per day on workdays and non-work days, respectively. These findings were slightly higher compared to a survey in the Swiss population from 2012, where 72% were sufficiently active in their leisure-time [39]. In the Swiss survey using a self-report questionnaire, the threshold to meet health recommendations was set at ≥150 minutes of MPA on five days or ≥75 minutes of HPA twice per week. In the present study, the self-report questionnaire (IPAQ) underreported MPA compared to the objective measurement (SWMA). This finding might explain the higher percentage of participants fulfilling the activity recommendations in this study compared to the Swiss survey of 2012. An explanation for the finding that LTPA on workdays was predictive for VO$_{2\text{max}}$ and participants being sufficiently active on workdays presented a higher VO$_{2\text{max}}$ could be that on workdays employees only have a little time window for exercising outside work, which increases the density of activities. In contrast, on non-work days physical activity may be more unstructured and less efficient because of the extended time availability (lower density of physical activity).

3.5.5 Clinical implications
The potential health benefits of a good cardiorespiratory fitness (high VO$_{2\text{max}}$ value) are well known. It reduces the risk of various diseases in the general population. This investigation has shown that OPA does not contribute to an improvement of VO$_{2\text{max}}$. In contrast, to maintain or improve VO$_{2\text{max}}$, intensive physical exercise in recreation in the range of high to very high intensity is required, as for example athletic cycling, soccer, martial arts, squash, inline skating or aerobics [40]. A low VO$_{2\text{max}}$ and insufficient physical activity have a strong impact on individuals’ wellbeing and all-cause mortality. Based on the present findings, it may be recommended to implement an attractive and intensive sports program at the workplace, such as lunch-time or after-work exercise in order to improve the overall health in the working population.

3.5.6 Findings in relation to physical activity assessment methodology
The two different methods for assessing physical activity in this study indicate a large discrepancy between subjective (IPAQ) and objective measurements (SWMA). These measurement variations are in accordance with a population-based sample of Swedish adults using an accelerometer [41]. In both studies, objective measurements of MPA were higher than those of the IPAQ and HPA measurements were reversed. Nevertheless, the multiple linear regression analysis with subjective activity parameters of the IPAQ revealed similar results in comparison with the analysis including objective SWMA data. Again, non-work related HPA was found to be a significant positive predictor of VO$_{2\text{max}}$. However, objective devices, such as the SWMA, are able to assess the contribution of physical activity to VO$_{2\text{max}}$ in a more differentiated way. Thus, objective measurement methods are more suitable for evaluating predictors of VO$_{2\text{max}}$ than subjective instruments.

3.5.7 Strengths and limitations
The present study had several strengths. The study sample included a wide range of manual and non-manual employees and represented a typical cross-section of the Swiss working population.
Furthermore, the measurement of physical activity and $VO_{2\text{max}}$ was conducted with objective instruments. The SWMA promises an accurate assessment of physical activity under non-ambulatory conditions. The inclusion of thermal and perspiration-related sensors in addition to the three-axis accelerometer provides a way to detect subtle increases in physical activity associated with low-intensity activities [19]. The results of a validation study against DLW showed in healthy adults a high intraclass correlation ($r=0.85$) and a low absolute error rate (8%, SD 7) [19]. Furthermore, the detection of non-wearing, resting and sleep time allow for more confidence in data consistency. However, there are also some limitations associated with the SWMA. The device has been shown to underestimate physical activity at high intensities [19]. Moreover, it was found to underestimate activities involving purely lower extremities, such as cycling, because of its wearing position on the upper arm [42]. In addition, it is not waterproof and lacks to detect water-based activities. A strength of the subjective IPAQ instrument is its ability to assess various dimensions of physical activity, such as duration, frequency, intensity and multiple domains of activity (work, leisure-time, transport, domestic and garden). Reliability and validity properties of the IPAQ were found to be at least as good as other established self-report physical activity measures [17]. The IPAQ is suitable for assessing large populations, since it is cost effective and simple in use [17]. However, only discrepant validation studies exist comparing self-report questionnaires to DLW [16]. Discrimination between moderate and vigorous activities within each domain of the IPAQ and the actual time spent in these activities have been shown to be challenging for subjects [43]. Another strength of this study were the strict exclusion criteria for recording days (e.g. measurement periods of <22 hours per day or <12 hours during wake-time were excluded from analysis). Thus, the recordings covered well typical workdays and non-work days. Nevertheless, the present study also had some weaknesses. Since only 4% of women participated in group 3 (high OPA), there is the need for further investigations to focus on females in this subgroup. Another limitation was that $VO_{2\text{max}}$ values were not directly measured, but predicted from the score, which participants reached in the 20-meter shuttle run test. For direct measurement of $VO_{2\text{max}}$, spiroergometry is considered to be the gold standard [44]. However, spiroergometry is labour-intensive, requires trained staff and is therefore not feasible for assessing large populations [45]. A recent study confirmed the validity of the 20-meter shuttle run test and concluded that it can accurately predict $VO_{2\text{max}}$ in healthy adults [46]. The results revealed significant correlations between the number of shuttles in the 20-meter shuttle run test and directly measured $VO_{2\text{max}}$ ($r=0.87$, $p<0.05$) as well as the velocity at which $VO_{2\text{max}}$ occurred ($r=0.93$, $p<0.05$) [46]. The present study was cross-sectional in nature, which provided a snapshot of the relation between physical activity and $VO_{2\text{max}}$. However, cause-effect relationships are difficult to ascertain. To overcome this limitation in future, longitudinal intervention studies are required.

3.5.8 Conclusions

The key finding of this cross-sectional investigation is that $VO_{2\text{max}}$ was not positively associated with OPA in a representative cohort of healthy Swiss employees (except negatively with MPA). In accordance with existing knowledge, $VO_{2\text{max}}$ showed a positive association with LTPA at high and very high intensity and with AEE. Furthermore, female gender, age, BMI, the ratio of $HR_{\text{max}}$ to $HR_{\text{rest}}$ and smoking were identified as independent predictors of $VO_{2\text{max}}$. The observed discrepancy between objective SWMA and subjective IPAQ data suggest that the measurement method might have a significant impact on the level of physical activity. Thus, studies investigating physical activity with a self-report questionnaire need to be interpreted with caution. For future studies it would be recommended to use an objective instrument for adequately evaluating the relationship between physical activity and health outcomes.
3.5.9 Acknowledgements

The authors of the present study would like to thank all employees for their study participation. In addition, the authors express their appreciation to “Gewerblich-industrielle Berufsfachschule Liestal” and “Kaserne Liestal” for their technical and equipment support. This study was financially supported by an unrestricted grant of the Swiss National Accident Insurance Fund (Suva) Lucerne.

3.5.10 Conflicts of Interest

David Miedinger is an employee of the funding organization (Suva). The funder provided support in the form of a project grant that covered salaries for the involved personnel at the Cantonal Hospital Baselland in Liestal as well as expenses for infrastructure and conducting the study, but did not have any role in the study design, data collection and analysis, decision to publish, or preparation of this manuscript. The participation of David Miedinger in this study was independent from the project grant and is covered by the contractual agreement between him and Suva that permits active participation in independently conducted research projects. The other authors have declared that no competing interests exist.
3.6 References


Chapter 4: Physical workload and work capacity across occupational groups


4.1 Abstract

Objectives: This study aimed to determine physical performance criteria of different occupational groups by investigating physical activity and energy expenditure in healthy Swiss employees in real-life workplaces on workdays and non-work days in relation to their aerobic capacity (VO$_2$max).

Methods: In this cross-sectional study, 337 healthy and full-time employed adults were recruited. Participants were classified (nine categories) according to the International Standard Classification of Occupations 1988 and merged into three groups with low-, moderate- and high-intensity occupational activity. Daily steps, energy expenditure, physical activity level in metabolic equivalents of task (METs) and activity at different intensities were measured using the SenseWear Mini armband on seven consecutive days (23 hours/day). VO$_2$max was determined by the 20-meter shuttle run test.

Results: Data of 303 subjects were considered for analysis (63% male, mean age: 33 yrs, SD 12, range: 18-61 yrs), 101 from the low-, 102 from the moderate- and 100 from the high-intensity group. At work, the high-intensity group showed higher energy expenditure, METs, steps and activity at all intensities than the other groups (p<0.001). There were no significant differences in physical activity between the occupational groups on non-work days. VO$_2$max did not differ across groups when stratified for gender. The upper workload limit was 21%, 29% and 44% of VO$_2$max in the low-, moderate- and high-intensity group, respectively. Men had a lower limit than women due to their higher VO$_2$max (26% vs. 37%), when all groups were combined.

Conclusions: While this study did confirm that the average workload limit is one third of VO$_2$max, it showed that the average is misrepresenting the actual physical work demands of specific occupational groups, and that it does not account for gender-related differences in relative workload. Therefore, clinical practice needs to consider these differences with regard to a safe return to work, particularly for the high-intensity group.

4.2 Introduction

Serious injury or illness can lead to a significant loss of working hours and substantial health care costs, when an employee is no longer able to perform his/her work appropriately. In 2014, about 226,000 people (4% of the insured population) received disability pension in Switzerland amounting to approximately 370 million US Dollars [1]. Adult recipients were predominantly male (53%) and older than 45 years [1]. Main reasons for disability were attributable to illness (79%), with a considerable proportion of musculoskeletal disorders (19%) [1]. Physical workload was found to be an independent risk factor for disability retirement due to musculoskeletal disorders [2]. When reintegrating patients into the work process after phases of sick leave, employers and insurance agencies may have to assess the work capacity of a person in order to adequately adjust the job profile [3]. The knowledge of workload and required work capacity could facilitate this process, because a successful resumption of work is highly dependent on these factors [3]. Since physical workload differs considerably between job assignments, it is mandatory to analyse a wide range of physical work requirements and to assess employees’ work capacity across occupational groups. Although several attempts have been made in this regard, there are few objective data available so far and no established reference values exist to
evaluate whether, when and how a return to work is possible [4]. Therefore, this study aimed to
describe the relationship between physical workload and work capacity in order to provide the basis for
guiding occupational rehabilitation measures.

Regarding workload, the Dictionary of Occupational Titles (DOT) [5] has been developed by the US
government in order to classify professions into five categories based on the amount of energy
expenditure (EE), as well as on the intensity and duration of lifting or carrying during work. However, the
DOT has not been based on quantitative work-related analyses and its validity has not been established
[4]. Work capacity can be assessed using functional capacity evaluations (FCEs) [6]. Soer et al. [3] applied
an evaluation system consisting of 12 work-related tests to establish functional capacity in healthy
employees. The assessment included various lifting and energetic exercises as well as coordination
tasks. From the test results, normative FCE values were developed for each DOT-category in healthy
adults, which could be compared to patient data in order to make return-to-work recommendations [3].
However, since validity of the DOT has not been proved, further analysis concerning workload
assessment is required. Previous studies measuring physical activity in employees have used
pedometers or accelerometers in combination with self-report questionnaires [7-9]. Step counting using
pedometers or accelerometers is widely accepted for assessing the amount of physical activity [10].
However, an accurate assessment of physical work requirements is not possible using these
instruments. The SenseWear Mini armband (SWMA) not only measures step counts, but also captures
EE with a multi-sensory system based on thermogenic properties [11]. The combination of multiple
sensors enables it to overcome limitations of conventional devices. By measuring heat produced by the
body, the armband can detect EE associated with load carrying and free-living physical activities [11].
Regarding work capacity, the application of FCE tools is time- and labour-intensive and may therefore
not be appropriate in a clinical or field context. In contrast, aerobic capacity or cardiorespiratory fitness
as measured as maximal oxygen uptake (VO$_{2\text{max}}$) has been shown to be an adequate indicator for
assessing individuals’ work capacity [12].

Objective workload data as measured by the SWMA in relation to work capacity as measured by VO$_{2\text{max}}$
have not been evaluated so far. Therefore, the primary aim of the present study was to determine
detailed activity profiles of different occupational groups by investigating aerobic capacity and physical
activity demands on workdays and non-work days in healthy Swiss employees. Furthermore, predictors
of physical workload were analysed. As a secondary objective, the International Physical Activity
Questionnaire (IPAQ) was co-evaluated in order to allow comparison to a simple assessment tool.

### 4.3 Materials and Methods

#### 4.3.1 Study subjects

From May 17, 2013 (first participant in) to February 11, 2015 (last participant in), 337 healthy and full-
time employed adults (≥80% full-time equivalent) from various companies of the Basel region,
Switzerland were recruited. Exclusion criteria were insufficient knowledge of the German language,
movement restrictions as well as diseases and accidents within the past three months that affected
productivity at the workplace. Furthermore, night shift workers could not take part in this study because
of their altered sleep, eating and physical activity behaviour. This investigation has been conducted
according to the Declaration of Helsinki and was approved by the local ethics committee
“Ethikkommission Nordwest- und Zentralschweiz” (EKNZ, 260/12) on December 21, 2012. Written
informed consent was obtained from all participants prior to study entry.
4.3.2 Study design and procedures

In this cross-sectional study, the aim was to recruit an equal distribution of subjects across different occupational groups. Based on this, appropriate companies were selected and addressed by a member of the research team, including medium sized corporations from the public sector (e.g. hospitals) as well as small sized private firms (e.g. construction companies). A permit from leading persons was requested to receive contact details for potentially recruitable employees, who were then informed and asked for study participation by phone or by email. At the first study visit, height and weight were reliably measured. Height was assessed without shoes by a medical measuring stick to the nearest mm (model Seca 217, measurement range: 20 to 205 cm, Seca AG, Reinach, Switzerland). The measurement of weight was performed on subjects in light clothing without shoes by a medical scale with an accuracy of 0.1 kg (model Seca 877, load capacity: 200 kg, Seca AG, Reinach, Switzerland). Body mass index (BMI) was calculated from measured height and weight (BMI = weight/height$^2$ [kg/m$^2$]). Subjects with a BMI of $\geq 25$ kg/m$^2$ were classified as overweight, and those with a BMI of $\geq 30$ kg/m$^2$ as obese [13]. In addition, various personal and job-related factors were recorded by a generic questionnaire, such as age, gender, nationality, marital status, smoking status, alcohol consumption, highest education, current profession, daily working hours, working time model, medication, psychotherapy, illnesses and accidents within the last three months. Based on the reported professions, subjects were classified (nine categories) according to the International Standard Classification of Occupations (ISCO-88) [14] and merged into three groups with low- (managers, scientists, office workers), moderate- (technicians, service workers, machine operators) and high-intensity occupational activity (agricultural workers, craftsmen, labourers) [15]. Prior to the observation period, subjects performed a 20-meter shuttle run test in order to measure aerobic capacity. During the subsequent week, participants wore the SWMA on seven consecutive days in order to objectively measure daily physical activity. It was ensured that the examination week consisted of at least three workdays. One week later at the second study visit, subjects completed the self-report IPAQ.

4.3.3 Physical activity assessment

**SenseWear Mini armband**

The SWMA (model MF-SW) is a small, lightweight and wireless multisensory activity monitor developed by BodyMedia Inc., Pittsburgh, Pennsylvania, USA (now Jawbone Inc., San Francisco, California, USA), which integrates a three-axis accelerometer along with other sensors such as heat flux, skin temperature and galvanic skin response. Validity was established by Johannsen et al. [11] comparing EE estimates of the SWMA against the criterion method doubly-labeled-water in healthy adults ($r=0.85$). Subjects were instructed to wear the SWMA on the upper left arm (triceps area) for seven consecutive days, including while sleeping, with the exception of one hour daily spent on personal hygiene. The first and the last incomplete measurement day, including the study visits, were not taken into account. Therefore, the investigated measurement period was five days, which had to consist of at least three workdays to be included in the analysis [16]. A day was considered as a whole workday, if participants worked cumulatively $\geq 6$ hours, and as a half workday in case of $3 \leq 6$ hours. Days with $< 3$ working hours were regarded as non-work days. Measurement days of $< 22$ hours per day or $< 12$ hours during wake-time were excluded from analysis [17, 18]. Information about workdays and non-work days as well as work-time and leisure-time on workdays was obtained from diaries participants filled in during the measurement period.
The physiological data collected by the armband’s sensors were processed by specific algorithms available in the SWMA software (BodyMedia, professional software V.7.0, algorithm V.2.2.4). Participants’ daily EE, metabolic equivalents of task (METs), physical activity duration at different intensities and number of steps were calculated. One MET corresponds to 3.5 ml O₂/kg/min [19]. Moderate physical activity (MPA) was defined as 3-6 METs, high physical activity (HPA) as 6-9 METs and very high physical activity (VHPA) as ≥9 METs. For all variables, average values were computed separately for workdays and non-work days as well as work-time and leisure-time on workdays. To have a measure for total recreation, mean values of leisure-time on workdays and non-work days were summed up and divided by the number of analysed days.

International Physical Activity Questionnaire

The IPAQ is a simple instrument for measuring physical activity at the population level. Validity and reliability were established in 12 different countries [20]. The German long version of the IPAQ designed for adults aged 15 to 69 years was administered to the participants. It includes 26 questions and assesses past-week frequency and duration of physical activity within the domains of work, leisure-time, transport, domestic and garden. Moreover, each domain consists of walking, moderate and vigorous activities. Continuous scores were calculated for MPA and HPA during work and total recreation. Regarding work, the duration of MPA (min/day) was determined by the sum of walking (3.3 METs) and moderate (4 METs) activity minutes from the work-domain [21]. For recreation, walking and moderate activity minutes from the domains of leisure-time, transport, domestic and garden were added up. To compute the duration of HPA (min/day) during work and recreation, vigorous (8 METs) activity minutes were considered within the corresponding domains [21].

4.3.4 Evaluation of aerobic capacity: 20-meter shuttle run test

The multistage 20-meter shuttle run is a common endurance fitness test to evaluate the maximal aerobic capacity of healthy adults [22]. It is simple in use, economical and large groups can be tested simultaneously. Validity of the one-minute stage version of the 20-meter shuttle run was established by Léger et al. [22], who compared the maximal shuttle run speed to VO₂max attained during a multistage treadmill test (r=0.90). Test-retest reliability was found to be very high in healthy adults (r=0.95) [23]. This test was conducted on a flat, non-slip surface. Participants were instructed to run back and forth between two lines, which were 20 meters apart, with a running velocity determined by audio signals [23]. Starting speed was 8.5 km/h and every minute (stage), speed was increased by 0.5 km/h until the subject could no longer keep the pace and did not reach the lines in time twice in a row [23]. The test result corresponded to the number of reached stages and shuttles and was used to predict VO₂max according to a validated table [24]. Four participants did not perform the 20-meter shuttle run test due to a resting systolic blood pressure >180 mmHg and were pairwise excluded from the corresponding analyses.

4.3.5 Determination of physical performance criteria

In order to determine physical performance criteria of different occupational groups, the ratio between workload and employees’ work capacity was analysed. METs during work-time assessed by the SWMA were used as objective measure of workload and VO₂max as measure of maximal work capacity. VO₂max was converted into METs [19]. To represent 95% of the normal range within each occupational group, workload was expressed as minus (lower limit) and plus (upper limit) two standard deviations (SD) [25]. The lower limit was considered as minimum work requirement for a particular job group. To describe
the individual’s work ability in relation to population-based values, the following formula was used: (Individual’s VO_{2\text{max}} / Mean VO_{2\text{max}_\text{Group}}) x Mean workload_{\text{Group}}.

4.3.6 Statistical analysis

Data were analysed using the software IBM SPSS Statistics (version 22.0). A p-value of <0.05 was considered as statistically significant. Data are presented as counts and percentages or mean and SD. The Shapiro-Wilk test was used to test whether data were normally distributed. To analyse differences across occupational groups, mean comparisons were performed using One-way Analysis of Variance or Kruskal-Wallis test, if appropriate. Categorical data were analysed with Chi-Square test. Multiple linear regression analyses were performed using the forward stepwise method in order to identify the most important predictors of physical workload. Validity of the regression model was established by checking essential assumptions. EE measured by the SWMA was subject to power calculation. Assuming a sample size of 100 subjects in each occupational group, there is a power of >90% to detect a mean difference of 500 kcal between any of these groups. This calculation was based on the assumption of a within group SD of 730 kcal and on a two-sided significance level of 5% [26].

4.4 Results

4.4.1 Subjects’ characteristics

Of the 337 recruited subjects 303 were considered for analysis, 101 from the low-, 102 from the moderate- and 100 from the high-intensity group. Age of the analysed participants ranged from 18 to 61 years (mean age: 33 yrs, SD 12) and two-thirds (n=190, 63%) were male. Mean BMI was 24 kg/m^2, SD 3, while 31% (n=95) were found to be overweight and 7% (n=21) were obese. Further details on study participants are given in Supplemental file 1.

Thirty-four subjects (10%) have worn the SWMA on less than three workdays and were therefore excluded from the entire analysis. Reasons for non-wearing or non-evaluation were: technical problems (n=4), illness during observation period (n=2), no paid occupation (n=5), no interest (n=15), loss of the armband (n=4), skin irritations (n=2) or sleep problems (n=2). Another 24 individuals had missing SWMA data on non-work days due to more workdays during observation period and were pairwise excluded from the corresponding analyses.

4.4.2 Classification of occupations

When examining METs during work-time across occupational categories (Figure 1), agricultural workers (n=9), craftsmen (n=78) and labourers (n=13) showed significantly higher METs than technicians (n=74) and service workers (n=24) (p<0.001), as well as managers (n=25), scientists (n=35) and office workers (n=41) (p<0.001). Technicians and service workers differed significantly from managers, scientists and office workers (p<0.001).
4.4.3 Physical activity data across occupational groups

Table 1 presents selected demographic characteristics, aerobic capacity and objective SWMA activity parameters across occupational groups. Univariate analyses revealed that the high-intensity group included more males and younger individuals compared to the other groups, whereas BMI did not differ significantly. Furthermore, employees of the high-intensity group showed higher activity levels on workdays (except VHPA). These differences mainly occurred during work-time, while in leisure-time VHPA and steps were reduced in the high-intensity group. In contrast, no significant differences in physical activity were found on non-work days (except EE). Physical activity parameters were generally higher on workdays compared to non-work days in the moderate- and high-intensity group, while it was the contrary in the low-intensity group. Moreover, work-time activity in comparison to leisure-time activity was increased in the high-intensity group, balanced in the moderate- and reduced in the low-intensity group. VO$_{2\text{max}}$ was significantly higher in the high-intensity group, but did not differ when stratified for gender (see Supplemental files 2 and 3 for more details). Mean VO$_{2\text{max}}$ was 36% higher in men (45 ml/kg/min, SD 8) than in women (33 ml/kg/min, SD 7).
Table 1: Aerobic capacity and objective SenseWear activity data across occupational groups (n=303)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-intensity group (n=101)</th>
<th>Moderate-intensity group (n=102)</th>
<th>High-intensity group (n=100)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>54 (53) N (%) or Mean (SD)</td>
<td>41 (40) N (%) or Mean (SD)</td>
<td>95 (95) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>38 (11) N (%) or Mean (SD)</td>
<td>35 (12) N (%) or Mean (SD)</td>
<td>27 (12) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI [kg/m²]</td>
<td>24 (3) N (%) or Mean (SD)</td>
<td>24 (4) N (%) or Mean (SD)</td>
<td>25 (3) N (%) or Mean (SD)</td>
<td>0.121</td>
</tr>
<tr>
<td>VO₂max [ml/kg/min]</td>
<td>39 (10) N (%) or Mean (SD)</td>
<td>38 (9) N (%) or Mean (SD)</td>
<td>43 (8) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EE Workday [kcal]</td>
<td>2276 (441) N (%) or Mean (SD)</td>
<td>2564 (852) N (%) or Mean (SD)</td>
<td>3563 (682) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Work-time [kcal]</td>
<td>1050 (282) N (%) or Mean (SD)</td>
<td>1251 (336) N (%) or Mean (SD)</td>
<td>2157 (461) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leisure-time [kcal]</td>
<td>1227 (334) N (%) or Mean (SD)</td>
<td>1313 (740) N (%) or Mean (SD)</td>
<td>1406 (455) N (%) or Mean (SD)</td>
<td>0.002</td>
</tr>
<tr>
<td>Non-work day [kcal]</td>
<td>2147 (831) N (%) or Mean (SD)</td>
<td>1981 (544) N (%) or Mean (SD)</td>
<td>2333 (667) N (%) or Mean (SD)</td>
<td>0.001</td>
</tr>
<tr>
<td>METs Workday [min]</td>
<td>156 (70) N (%) or Mean (SD)</td>
<td>215 (107) N (%) or Mean (SD)</td>
<td>405 (135) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Work-time [min]</td>
<td>52 (42) N (%) or Mean (SD)</td>
<td>109 (78) N (%) or Mean (SD)</td>
<td>294 (109) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leisure-time [min]</td>
<td>105 (46) N (%) or Mean (SD)</td>
<td>107 (55) N (%) or Mean (SD)</td>
<td>111 (49) N (%) or Mean (SD)</td>
<td>0.559</td>
</tr>
<tr>
<td>Non-work day [min]</td>
<td>174 (90) N (%) or Mean (SD)</td>
<td>170 (103) N (%) or Mean (SD)</td>
<td>191 (121) N (%) or Mean (SD)</td>
<td>0.623</td>
</tr>
<tr>
<td>HPA Workday [min]</td>
<td>10 (10) N (%) or Mean (SD)</td>
<td>12 (17) N (%) or Mean (SD)</td>
<td>28 (22) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Work-time [min]</td>
<td>1 (2) N (%) or Mean (SD)</td>
<td>3 (7) N (%) or Mean (SD)</td>
<td>19 (18) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leisure-time [min]</td>
<td>9 (10) N (%) or Mean (SD)</td>
<td>9 (13) N (%) or Mean (SD)</td>
<td>9 (10) N (%) or Mean (SD)</td>
<td>0.780</td>
</tr>
<tr>
<td>Non-work day [min]</td>
<td>11 (15) N (%) or Mean (SD)</td>
<td>10 (23) N (%) or Mean (SD)</td>
<td>13 (17) N (%) or Mean (SD)</td>
<td>0.147</td>
</tr>
<tr>
<td>VHPA Workday [min]</td>
<td>2.3 (5.4) N (%) or Mean (SD)</td>
<td>2.1 (4.2) N (%) or Mean (SD)</td>
<td>1.8 (5.5) N (%) or Mean (SD)</td>
<td>0.339</td>
</tr>
<tr>
<td>Work-time [min]</td>
<td>0.0 (0.1) N (%) or Mean (SD)</td>
<td>0.1 (1.0) N (%) or Mean (SD)</td>
<td>0.4 (2.0) N (%) or Mean (SD)</td>
<td>0.001</td>
</tr>
<tr>
<td>Leisure-time [min]</td>
<td>2.4 (5.5) N (%) or Mean (SD)</td>
<td>1.9 (4.0) N (%) or Mean (SD)</td>
<td>1.5 (5.1) N (%) or Mean (SD)</td>
<td>0.040</td>
</tr>
<tr>
<td>Non-work day [min]</td>
<td>2.0 (5.9) N (%) or Mean (SD)</td>
<td>2.5 (7.3) N (%) or Mean (SD)</td>
<td>1.9 (9.0) N (%) or Mean (SD)</td>
<td>0.688</td>
</tr>
<tr>
<td>Steps Workday</td>
<td>9777 (3105) N (%) or Mean (SD)</td>
<td>11'674 (3661) N (%) or Mean (SD)</td>
<td>15'057 (4197) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Work-time</td>
<td>3650 (1760) N (%) or Mean (SD)</td>
<td>5824 (2514) N (%) or Mean (SD)</td>
<td>10'131 (3804) N (%) or Mean (SD)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leisure-time</td>
<td>6127 (2885) N (%) or Mean (SD)</td>
<td>5850 (2474) N (%) or Mean (SD)</td>
<td>4926 (2243) N (%) or Mean (SD)</td>
<td>0.002</td>
</tr>
<tr>
<td>Non-work day</td>
<td>8764 (3808) N (%) or Mean (SD)</td>
<td>9212 (4507) N (%) or Mean (SD)</td>
<td>9039 (9089) N (%) or Mean (SD)</td>
<td>0.181</td>
</tr>
</tbody>
</table>

BMI, body mass index; EE, energy expenditure; METs, metabolic equivalents of task; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SD, standard deviation; VO₂max, maximal oxygen uptake during 20-meter shuttle run test. Significant p-values are highlighted in bold.
Figure 2 illustrates subjective IPAQ data across occupational groups in comparison to objective SWMA data. Based on the IPAQ, MPA and HPA at work were again significantly higher in the high-intensity group compared to the other groups. However, HPA in recreation was reduced in the high-intensity group, while no significant difference was found with the SWMA. In total subjects, MPA at work was underreported by two-thirds using the IPAQ compared to the SWMA (51 min/day, SD 73 vs. 151 min/day, SD 131), while MPA in recreation was underreported by 55% (58 min/day, SD 46 vs. 130 min/day, SD 59). In contrast, HPA was overreported by 75% during work (14 min/day, SD 36 vs. 8 min/day, SD 14) and in recreation by 60% (16 min/day, SD 21 vs. 10 min/day, SD 11).

**Figure 2**: Comparison of objective SWMA activity data with subjective IPAQ activity data.

HPA_Recreation_IPAQ / HPA_Work_IPAQ, physical activity at high intensity (8 METs) based on the International Physical Activity Questionnaire; HPA_Recreation_SWMA / HPA_Work_SWMA, physical activity at high intensity (6-9 METs) measured by the SenseWear Mini armband; MPA_Recreation_IPAQ / MPA_Work_IPAQ, physical activity at moderate intensity (3 METs: inside chores, 3.3 METs: walking, 4 METs: moderate activity at work, yard work or in leisure-time, 5.5 METs: vigorous yard chores, 6 METs: cycle for transport) based on the International Physical Activity Questionnaire; MPA_Recreation_SWMA / MPA_Work_SWMA, physical activity duration at moderate intensity (3-6 METs) measured by the SenseWear Mini armband.

* Intergroup comparisons (low- vs. moderate- vs. high-intensity group) revealed highly significant differences (p<0.001).
4.4.4 Determination of physical performance criteria

In Table 2, mean values of VO$_{2\text{max}}$, and physical workload as well as lower and upper workload limits are presented across occupational groups, stratified for gender. In total subjects, mean workload was about 23% of VO$_{2\text{max}}$ (lower limit: 14% - upper limit: 31%). The ratio of workload to maximal work capacity was inferior in the low-intensity group (16% (10% - 21%)) compared to the moderate- (20% (11% - 29%)) and high-intensity group (32% (19% - 44%)). Moreover, men exerted a lower relative workload (19% (11% - 26%)) than women (26% (16% - 37%)), when all groups were combined.

### Table 2: Ratio of workload to maximal work capacity according to occupational group and gender

<table>
<thead>
<tr>
<th></th>
<th>VO$_{2\text{max}}$ [METs]</th>
<th>Workload [METs]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male (n=190)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-intensity group</td>
<td>12.8 (2.3)</td>
<td>1.7 (13.3)</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>1.1 (8.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.3 (18.0)</td>
</tr>
<tr>
<td>Moderate-intensity</td>
<td>12.9 (2.7)</td>
<td>2.2 (17.1)</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.2 (9.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2 (24.8)</td>
</tr>
<tr>
<td>High-intensity group</td>
<td>12.7 (2.1)</td>
<td>3.3 (26.0)</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>2.1 (16.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.5 (35.4)</td>
</tr>
<tr>
<td><strong>Female (n=113)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-intensity group</td>
<td>9.4 (2.2)</td>
<td>1.7 (18.1)</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>1.1 (11.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.3 (24.5)</td>
</tr>
<tr>
<td>Moderate-intensity</td>
<td>9.4 (1.8)</td>
<td>2.2 (23.4)</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.2 (12.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2 (34.0)</td>
</tr>
<tr>
<td>High-intensity group</td>
<td>8.1 (1.9)</td>
<td>3.0 (37.0)</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>1.8 (22.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2 (51.9)</td>
</tr>
</tbody>
</table>

METs, metabolic equivalents of task; SD, standard deviation; VO$_{2\text{max}}$, maximal oxygen uptake during 20-meter shuttle run test.

4.4.5 Predictors of physical workload

Forward stepwise multiple linear regression analyses with physical workload as dependent variable are shown in Table 3. In model 1, objective SWMA parameters were included as predictors, while model 2 considered subjective IPAQ variables. The overall fit of model 1 was very high explaining 93% of variance in workload. METs increased from the low- to the moderate- and high-intensity group as shown by the positive correlations. MPA, HPA and VHPA at work were also found to be positively associated with METs. In contrast, daily working hours, age, flextime and VO$_{2\text{max}}$ showed a negative relationship with physical workload. Based on the results of multiple linear regressions, this study has generated the following prediction equation for model 1:

\[
\text{Workload [METs]} = 2.247 + (0.005 \times \text{MPA work [min/day]}) + (0.007 \times \text{HPA work [min/day]}) + (0.234 \times \text{Occupational group; Low-intensity = 0, High-intensity = 1}) + (0.156 \times \text{Occupational group; Low-intensity = 0, Moderate-intensity = 1}) + (0.056 \times \text{Working hours [h/day]}) + (0.031 \times \text{VHPA work [min/day]}) - (0.086 \times \text{Flextime; No = 0, Yes = 1}) - (0.003 \times \text{Age [yrs]}) - (0.010 \times \text{VO}_{2\text{max}} \times \text{METs}).
\]

The adjusted R$^2$ of model 2 was slightly lower, but still high with 0.74. The displayed correlations were similar to model 1 with the exception of BMI and gender, which now revealed a significant negative association with workload.
Table 3: Forward stepwise multiple linear regressions with workload [METs] as dependent variable

**Objective SenseWear Mini armband data**

<table>
<thead>
<tr>
<th>Model 1: n=297, adjusted $R^2=0.93$</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
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<tr>
<td>MPA work [min/day]</td>
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<td>0.000</td>
<td>0.736</td>
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<tr>
<td>HPA work [min/day]</td>
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<tr>
<td>Low- vs. High-intensity group</td>
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</tr>
<tr>
<td>Low- vs. Moderate-intensity group</td>
<td>0.156</td>
<td>0.033</td>
<td>0.090</td>
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</tr>
<tr>
<td>Working hours [h/day]</td>
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<td>0.015</td>
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</tr>
<tr>
<td>VHPA work [min/day]</td>
<td>0.031</td>
<td>0.010</td>
<td>0.049</td>
<td>0.002</td>
</tr>
<tr>
<td>Flextime: No vs. Yes</td>
<td>-0.086</td>
<td>0.031</td>
<td>-0.050</td>
<td>0.006</td>
</tr>
<tr>
<td>Age [yrs]</td>
<td>-0.003</td>
<td>0.001</td>
<td>-0.045</td>
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<tr>
<td>VO$_{2\text{max}}$ [METs]</td>
<td>-0.010</td>
<td>0.005</td>
<td>-0.034</td>
<td>0.039</td>
</tr>
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</table>

**Subjective International Physical Activity Questionnaire data**

<table>
<thead>
<tr>
<th>Model 2: n=296, adjusted $R^2=0.74$</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$p$-value</th>
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<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>4.395</td>
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<td>Low- vs. High-intensity group</td>
<td>1.114</td>
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<tr>
<td>Low- vs. Moderate-intensity group</td>
<td>0.326</td>
<td>0.065</td>
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<tr>
<td>BMI [kg/m$^2$]</td>
<td>-0.052</td>
<td>0.008</td>
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<tr>
<td>MPA work [min/day]</td>
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<td>0.000</td>
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<td>Flextime: No vs. Yes</td>
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<td>-0.123</td>
<td>0.001</td>
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<td>Age [yrs]</td>
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</tr>
<tr>
<td>Gender: Male vs. Female</td>
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</tr>
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<td>Working hours [h/day]</td>
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<td>-0.065</td>
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<tr>
<td>VO$_{2\text{max}}$ [METs]</td>
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<td>0.034</td>
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<td>HPA work [min/day]</td>
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<td>0.001</td>
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B, unstandardized regression coefficient; $\beta$, standardized beta coefficient; BMI, body mass index; METs, metabolic equivalents of task; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SE, standard error; VO$_{2\text{max}}$, maximal oxygen uptake during 20-meter shuttle run test.

**Model 1**: Included predictors were Gender (Male vs. Female), Age, BMI, VO$_{2\text{max}}$, Occupational group (Low- vs. Moderate-intensity group, Low- vs. High-intensity group), Daily working hours, Daily sleeping hours, Flextime (No vs. Yes), Shift work (No vs. Yes), Weekend work (No vs. Yes), Min/day of MPA, HPA, VHPA at work (measured with the SenseWear Mini armband).

**Model 2**: Included predictors were Gender (Male vs. Female), Age, BMI, VO$_{2\text{max}}$, Occupational group (Low- vs. Moderate-intensity group, Low- vs. High-intensity group), Daily working hours, Daily sleeping hours, Flextime (No vs. Yes), Shift work (No vs. Yes), Weekend work (No vs. Yes), Min/day of MPA, HPA at work (assessed by the International Physical Activity Questionnaire).
### Supplemental file 1: Personal and job-related factors across occupational groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n=303) Mean (SD)</th>
<th>Low-intensity group (n=101) Mean (SD)</th>
<th>Moderate-intensity group (n=102) Mean (SD)</th>
<th>High-intensity group (n=100) Mean (SD)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working hours [h/day]</td>
<td>8.8 (0.8)</td>
<td>8.9 (1.0)</td>
<td>8.7 (0.9)</td>
<td>8.6 (0.5)</td>
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<td><strong>Variable</strong></td>
<td><strong>N (%)</strong></td>
<td><strong>N (%)</strong></td>
<td><strong>N (%)</strong></td>
<td><strong>N (%)</strong></td>
<td><strong>p-value</strong></td>
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<td>Nationality</td>
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<td>European</td>
<td>70 (23)</td>
<td>22 (22)</td>
<td>23 (22)</td>
<td>25 (25)</td>
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<tr>
<td>Other</td>
<td>12 (4)</td>
<td>2 (2)</td>
<td>3 (3)</td>
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<td>Marital status</td>
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<td>Single</td>
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<td>56 (55)</td>
<td>65 (64)</td>
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<td>Married</td>
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<td>26 (25)</td>
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<td>Divorced</td>
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<td>Smoking status</td>
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<td>Never smoker</td>
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<td>61 (60)</td>
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<td>Ex-smoker</td>
<td>60 (20)</td>
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<td>Current smoker</td>
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<td>Never</td>
<td>46 (15)</td>
<td>9 (9)</td>
<td>22 (22)</td>
<td>15 (15)</td>
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<tr>
<td>1-x times per month</td>
<td>146 (48)</td>
<td>52 (51)</td>
<td>51 (50)</td>
<td>43 (43)</td>
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<td>1-x times per week</td>
<td>108 (36)</td>
<td>40 (40)</td>
<td>28 (27)</td>
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<td>Daily</td>
<td>3 (1)</td>
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<td>Highest education</td>
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</tr>
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<td>Basic school</td>
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<td>Apprenticeship</td>
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<td>42 (41)</td>
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<td>Vocational school</td>
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<td>Maturity or diploma</td>
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<td>33 (32)</td>
<td>1 (1)</td>
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<tr>
<td>Flextime</td>
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<td>9 (9)</td>
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</tr>
<tr>
<td>Fixtime</td>
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<td>35 (35)</td>
<td>68 (67)</td>
<td>88 (88)</td>
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</tr>
<tr>
<td>Shift work</td>
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<td>2 (2)</td>
<td>17 (17)</td>
<td>6 (6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weekend work</td>
<td>59 (20)</td>
<td>12 (12)</td>
<td>38 (37)</td>
<td>9 (9)</td>
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</tr>
<tr>
<td>Medication</td>
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<td>Illnesses/Accidents</td>
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<td>20 (20)</td>
<td>26 (26)</td>
<td>23 (23)</td>
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<td>19 (19)</td>
<td>21 (21)</td>
<td>8 (8)</td>
<td>0.030</td>
</tr>
</tbody>
</table>

SD, standard deviation. Significant p-values are highlighted in bold.
### Supplemental file 2: Aerobic capacity and SenseWear activity data across job groups in men (n=190)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-intensity group (n=55)</th>
<th>Moderate-intensity group (n=40)</th>
<th>High-intensity group (n=95)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VO$_{2\text{max}}$ [ml/kg/min]</strong></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>Workday</td>
<td>45 (8)</td>
<td>45 (10)</td>
<td>44 (7)</td>
<td>0.795</td>
</tr>
<tr>
<td><strong>EE [Workday kcal]</strong></td>
<td>2534 (366)</td>
<td>3113 (1072)</td>
<td>3630 (630)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Work-time [kcal]</strong></td>
<td>1180 (279)</td>
<td>1421 (366)</td>
<td>2198 (434)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Leisure-time [kcal]</strong></td>
<td>1355 (344)</td>
<td>1692 (1033)</td>
<td>1432 (452)</td>
<td>0.032</td>
</tr>
<tr>
<td><strong>Non-work day [kcal]</strong></td>
<td>2303 (533)</td>
<td>2261 (586)</td>
<td>2381 (650)</td>
<td>0.785</td>
</tr>
<tr>
<td><strong>METs</strong></td>
<td>Workday</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td><strong>Workday</strong></td>
<td>2.0 (0.3)</td>
<td>2.3 (0.4)</td>
<td>2.8 (0.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Work-time</strong></td>
<td>1.7 (0.3)</td>
<td>2.2 (0.5)</td>
<td>3.3 (0.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Leisure-time</strong></td>
<td>2.4 (0.5)</td>
<td>2.3 (0.5)</td>
<td>2.3 (0.5)</td>
<td>0.344</td>
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<tr>
<td><strong>Non-work day</strong></td>
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<td>2.1 (0.6)</td>
<td>2.1 (0.6)</td>
<td>0.834</td>
</tr>
<tr>
<td><strong>MPA</strong></td>
<td>Workday [min]</td>
<td>161 (77)</td>
<td>241 (118)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Work-time [min]</strong></td>
<td>56 (50)</td>
<td>117 (86)</td>
<td>298 (109)</td>
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<tr>
<td><strong>Leisure-time [min]</strong></td>
<td>106 (49)</td>
<td>124 (63)</td>
<td>112 (49)</td>
<td>0.423</td>
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<tr>
<td><strong>Non-work day [min]</strong></td>
<td>179 (95)</td>
<td>186 (106)</td>
<td>193 (121)</td>
<td>0.969</td>
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<tr>
<td><strong>HPA</strong></td>
<td>Workday [min]</td>
<td>11 (12)</td>
<td>17 (20)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Work-time [min]</strong></td>
<td>1 (3)</td>
<td>6 (11)</td>
<td>19 (18)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Leisure-time [min]</strong></td>
<td>10 (11)</td>
<td>11 (12)</td>
<td>10 (11)</td>
<td>0.837</td>
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<tr>
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<td>14 (33)</td>
<td>13 (17)</td>
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<td><strong>VHPA</strong></td>
<td>Workday [min]</td>
<td>3 (6)</td>
<td>4 (5)</td>
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<td><strong>Work-time [min]</strong></td>
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<td>0 (2)</td>
<td>0 (2)</td>
<td>0.074</td>
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<tr>
<td><strong>Leisure-time [min]</strong></td>
<td>3 (6)</td>
<td>3 (5)</td>
<td>1 (5)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Non-work day [min]</strong></td>
<td>1 (4)</td>
<td>4 (10)</td>
<td>2 (9)</td>
<td>0.755</td>
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<tr>
<td><strong>Steps</strong></td>
<td>Workday</td>
<td>9555 (3118)</td>
<td>12'245 (3826)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Work-time</strong></td>
<td>3629 (2014)</td>
<td>6071 (2598)</td>
<td>10'366 (3737)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Leisure-time</strong></td>
<td>5926 (3077)</td>
<td>6175 (2986)</td>
<td>4910 (2271)</td>
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<tr>
<td><strong>Non-work day</strong></td>
<td>8478 (3644)</td>
<td>10'164 (5868)</td>
<td>9239 (9289)</td>
<td>0.277</td>
</tr>
</tbody>
</table>

EE, energy expenditure; METs, metabolic equivalents of task; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SD, standard deviation; VO$_{2\text{max}}$, maximal oxygen uptake during 20-meter shuttle run test. Significant p-values are highlighted in bold.
Supplemental file 3: Aerobic capacity and SenseWear activity data across job groups in women (n=113)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-intensity group (n=46)</th>
<th>Moderate-intensity group (n=62)</th>
<th>High-intensity group (n=5)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO(_{2\text{max}}) [ml/kg/min]</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
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<tr>
<td>EE [kcal]</td>
<td>33 (8)</td>
<td>33 (6)</td>
<td>29 (7)</td>
<td>0.002</td>
</tr>
<tr>
<td>Work-time [kcal]</td>
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<td>2210 (377)</td>
<td>2294 (276)</td>
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</tr>
<tr>
<td>Leisure-time [kcal]</td>
<td>895 (194)</td>
<td>1142 (265)</td>
<td>1379 (155)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Non-work day [kcal]</td>
<td>1073 (248)</td>
<td>1068 (262)</td>
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<tr>
<td>METs [kcal]</td>
<td>1968 (1055)</td>
<td>1808 (439)</td>
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<td>Workday [min]</td>
<td>150 (62)</td>
<td>198 (97)</td>
<td>299 (113)</td>
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<td>Work-time [min]</td>
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<td>103 (73)</td>
<td>214 (72)</td>
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</tr>
<tr>
<td>Leisure-time [min]</td>
<td>104 (43)</td>
<td>95 (45)</td>
<td>85 (45)</td>
<td>0.302</td>
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<td>Non-work day [min]</td>
<td>168 (85)</td>
<td>161 (100)</td>
<td>154 (116)</td>
<td>0.535</td>
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<td>8 (14)</td>
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</tr>
<tr>
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<td>2 (3)</td>
<td>19 (24)</td>
<td>0.030</td>
</tr>
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<td>7 (14)</td>
<td>2 (2)</td>
<td>0.138</td>
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<td>8 (12)</td>
<td>6 (10)</td>
<td>0.362</td>
</tr>
<tr>
<td>VHPA [min]</td>
<td>2 (4)</td>
<td>1 (3)</td>
<td>0 (0)</td>
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</tr>
<tr>
<td>Work-time [min]</td>
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<td>0 (0)</td>
<td>0 (0)</td>
<td>1.000</td>
</tr>
<tr>
<td>Leisure-time [min]</td>
<td>2 (5)</td>
<td>1 (3)</td>
<td>0 (0)</td>
<td>0.093</td>
</tr>
<tr>
<td>Non-work day [min]</td>
<td>3 (8)</td>
<td>2 (5)</td>
<td>0 (0)</td>
<td>0.529</td>
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<tr>
<td>Steps [Steps]</td>
<td>10'042 (3103)</td>
<td>11'305 (3533)</td>
<td>10'911 (3291)</td>
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</tr>
<tr>
<td>Work-time [Steps]</td>
<td>3674 (1419)</td>
<td>5665 (2466)</td>
<td>5672 (1944)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leisure-time [Steps]</td>
<td>6368 (2651)</td>
<td>5641 (2079)</td>
<td>5239 (1805)</td>
<td>0.463</td>
</tr>
<tr>
<td>Non-work day [Steps]</td>
<td>9093 (4002)</td>
<td>8624 (3338)</td>
<td>5599 (3094)</td>
<td>0.144</td>
</tr>
</tbody>
</table>

EE, energy expenditure; METs, metabolic equivalents of task; MPA / HPA / VHPA, physical activity duration at moderate (3-6 METs) / high (6-9 METs) / very high (≥9 METs) intensity; SD, standard deviation; VO\(_{2\text{max}}\), maximal oxygen uptake during 20-meter shuttle run test. Significant p-values are highlighted in bold.
4.5 Discussion

This cross-sectional study found that the high-intensity group including manual labourers, agricultural workers and craftsmen showed a higher proportion of MPA, HPA, VHPA and steps, as well as EE and METs measured by the SWMA on workdays during work-time than the other occupational groups. VO\textsubscript{2max} was also greater in this group, but did not differ when stratified for gender. In contrast, during leisure-time on workdays, VHPA and steps were reduced in the high-intensity group compared to the low- and moderate-intensity group. No significant differences in physical activity between the groups were found on non-work days (except EE). In total subjects, mean workload as determined by METs was 23\% of VO\textsubscript{2max} (lower limit: 14\% - upper limit: 31\%). The ratio of workload to maximal work capacity increased from the low- to the moderate- and high-intensity group. Moreover, the relative workload exerted by males was lower than by females due to their higher VO\textsubscript{2max}. Furthermore, higher-intensity groups, MPA, HPA and VHPA at work were identified as positive predictors of physical workload, while daily working hours, age, flextime and VO\textsubscript{2max} showed a negative association. Multiple linear regression analysis including subjective activity variables revealed similar correlations as with objective parameters, but presented a slightly lower adjusted R\textsuperscript{2}. However, when directly comparing subjective and objective activity data, MPA during work and recreation were underreported using the IPAQ, whereas work and non-work related HPA were overreported.

4.5.1 Physical activity data across occupational groups

As the analyses show, occupational groups differed considerably in physical activity and EE. The present findings are similar to those of previous studies using pedometers or accelerometers. Steele & Mummery [7] reported in Australian workers a gradation in step counts during work-time from professionals to white-collar and blue-collar workers. Mean step counts were lower by 1000-2000 steps in each group than in this study. However, they used a spring-levered pedometer that is known to be compromised in accuracy at slow walking speeds [27]. Similarly, a representative sample of Swiss workers indicated that on workdays fewer steps were accumulated in sitting occupations compared to standing occupations and physically active jobs [28]. Miller & Brown [8] also detected reduced step counts on weekdays in professionals compared to technical and blue-collar workers. Consistent with the present findings, no significant differences were found on weekend days. The lack of difference in physical activity outside work was confirmed by Tigbe et al. [29]. Previous studies showed in sedentary occupations that leisure-time included more physical activity than work-time [9, 30] which is in line with the present results. However, this study showed that leisure-time activity was not increased in the low-intensity group compared to the other groups. Therefore, when total activity was considered, employees of the moderate- and high-intensity group accumulated more physical activity. This suggests that subjects in jobs with low physical demands do not fully compensate for their inactivity at work during leisure-time.

Regarding aerobic capacity, VO\textsubscript{2max} values were increased in the high-intensity group compared to the other groups, but did not differ when stratified for gender. This might be explained by the fact that 95\% of subjects in the high-intensity group were men. Therefore, it is likely that this group had an increased aerobic capacity because of the large proportion of males, whose mean VO\textsubscript{2max} was considerably higher than those of females. This could also be the reason for the higher EE on non-work days, while the other activity parameters did not differ significantly. Men in general have more skeletal muscle mass in comparison to women in both absolute terms and relative to body mass, which results in an increased EE [31].
4.5.2 Determination of physical performance criteria

Based on the observations, this study could confirm previous findings expressing physical workload as percentage of VO$_{2\text{max}}$. For example, Jorgensen et al. [32] found that the upper limit for an eight-hour workday of mixed physical work was 30-35% of VO$_{2\text{max}}$, which is consistent with the present results (31%). However, job-dependent differences were not taken into account. This investigation found that the relative workload was 1.5 times and twice as high in the high-intensity group (44%) compared to the moderate- (29%) and low-intensity (21%) group. Another study suggested that the overall workload limit for jobs with high physical demands might be within the range of 33-50% of VO$_{2\text{max}}$ [33]. While this study did confirm these values, it showed that women had a considerably higher limit (52%) than men (35%) due to their lower VO$_{2\text{max}}$. These differences in relative workload need to be accounted for in clinical practice with regard to a safe return to work, particularly for the high-intensity group.

4.5.3 Predictors of physical workload

This is the first study analysing predictors of physical workload objectively measured by the SWMA. Evidently, workload increased from the low- to the moderate- and high-intensity group. More MPA, HPA and VHPA during work also increased workload, while flextime could decrease workload. Kelloway & Gottlieb [34] confirmed that work arrangements involving flexibility promoted women’s well-being by increasing perceived control over time and reducing perceived job overload. With increasing age and longer working hours workload needs to be reduced, which is consistent with Wu & Wang [35]. BMI and gender did not show a significant association with workload. In this study, women presented equal absolute METs during work as men, but had a higher relative workload due to their lower aerobic capacity. VO$_{2\text{max}}$ showed a negative association with workload. However, it was just slightly significant and therefore not one of the most important predictors. This is an interesting finding, since up to now work recommendations were primarily based on VO$_{2\text{max}}$. To facilitate the implementation of the study results, the generated regression equation for predicting physical workload could be used to develop user-friendly calculators (e.g. mobile apps). This would enable different stakeholders (e.g. employees, employers and insurance agencies) to evaluate individuals’ physical workload in a low effort way.

For clinical practice, it might be valuable to use predictors measured by a simple instrument, rather than by the SWMA. When including self-report IPAQ data, similar correlations were revealed as with objective data. However, the two methods for measuring physical activity showed large discrepancies. Subjective MPA data were lower than objective data and HPA were reversed. These measurement variations are in line with a Swedish study comparing the IPAQ with an accelerometer [36].

4.5.4 Generalizability of results

Study subjects were equally distributed across groups with low-, moderate- and high-intensity occupational activity. The present results showed that the three groups differed significantly from each other in terms of physical workload (METs) and confirmed the applied classification. Just machine operators showed a high variance, which could be explained by the small number of subjects (n=4, 1%). However, this corresponds to the Swiss working population (4%) [37]. The percentage of women in the present study was similar to data of the Swiss Labour Force in the low- and moderate-intensity group, but lower in the high-intensity group [37]. However, 78% of subjects in this group were craftsmen. When considering only craftsmen, the female percentages were comparable. Furthermore, more subjects between 18-39 years and fewer subjects between 40-65 years were included in this study [37]. This might be due to the fact that younger people were more motivated to participate. Nevertheless, a
healthy worker effect appears to be unlikely, since the percentage of overweight and obesity was in accordance with the prevalence in Switzerland in 2012 [38]. Moreover, mean VO$_{2\text{max}}$ values of total, male and female subjects corresponded to a previous population-based study in US employees [39].

4.5.5 Strengths and limitations

The study sample included a wide range of manual and non-manual employees and represented a typical cross-section of the Swiss working population, but the proportion of women was only 5% in the high-intensity group. In order to strengthen the observed findings, future studies need to focus on females in this subgroup. Furthermore, the measurement of physical activity and aerobic capacity was conducted with objective methods. To the authors’ knowledge, this is the first study determining gender-related and job-specific physical performance criteria in healthy employees based on objective workload data derived in real-life workplaces. These physical performance criteria build a good basis for future investigations, but need to be validated for other populations. The two different instruments for assessing physical activity indicated a substantial discrepancy between subjective and objective measurements. The SWMA promises an accurate assessment of physical activity under non-ambulatory conditions [11]. The inclusion of thermal and perspiration-related sensors allows detecting subtle increases in physical activity associated with low intensities. Furthermore, this device ensures a sensitive determination of acceleration provoked by muscle power or externally by a vehicle or gravitation [11]. The recording of non-wearing, resting and sleep time also allow for more confidence in data consistency. However, the device has been shown to underestimate activities at high intensities and those involving purely lower extremities, such as cycling, because of its wearing position on the upper arm [11, 40]. In addition, it is not waterproof and lacks to detect water-based activities. A strength of the IPAQ is its ability to assess various dimensions of physical activity, such as duration, frequency, intensity and different domains [20]. The IPAQ is suitable for the implementation in large populations, because it is cost effective and simple in use. However, there is evidence that subjects may find it difficult to differentiate between moderate and vigorous intensity and to identify the actual time spent in these activities [41]. Therefore, objective measurement methods, such as the SWMA, may be preferably used to determine detailed activity profiles across occupational groups.

4.5.6 Clinical implications

This study provides objective information about employees’ work capacity and physical work requirements of different occupational groups. Based on the determined physical performance criteria, it can be evaluated whether somebody is able to resume his/her previous work after phases of sick leave. If a patient’s work ability in comparison to population-based values is sufficient to meet the minimum work requirements (lower workload limit) of his/her corresponding job group, then the patient is likely to return to work successfully. For example, a male patient previously working in the high-intensity group would like to go back to his former job after illness. He performed a 20-meter shuttle run test and achieved a VO$_{2\text{max}}$ of 8 METs. This value divided by the mean VO$_{2\text{max}}$ of the high-intensity group (12.7 METs) and multiplied by the corresponding mean METs (3.3 METs) results in 2.08 METs. Comparing this value to the lower limit of the high-intensity group (2.1 METs) suggests that this patient is borderline for resuming his work and his job profile may need to be adjusted. This example elucidates how data from this study may help to improve intervention strategies and clinicians’ return-to-work recommendations. An optimized reintegration process may reduce future loss of working hours and related health care costs.
4.5.7 Conclusions

In a representative sample of a working population, this study found that subjects in jobs with high physical demands had increased activity levels on workdays, while physical activity on non-work days did not differ across occupational groups. Individuals in sedentary occupations did not appear to fully compensate for their inactivity at work during leisure-time. $\text{VO}_{2\text{max}}$ was considerably higher in men compared to women, but did not differ across groups when stratified for gender. Discrepancies between subjectively rated and objectively measured activity data recommend using objective methods for accurately determining activity profiles across occupational groups. While this study did confirm that the average workload limit is one third of $\text{VO}_{2\text{max}}$, it showed that the average is misrepresenting the actual physical work demands of specific occupational groups, and that it does not account for gender-related differences in relative workload. The determined job- and gender-specific physical performance criteria may help to develop future guidelines for a safe return to work. Results of multiple linear regressions suggest considering various personal and job-related factors for evaluating physical workload, besides $\text{VO}_{2\text{max}}$. In a further step, the generated regression equation may be used to develop simple tools for determining individuals’ workload, such as calculators or mobile apps.

4.5.8 Acknowledgements

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4.5.9 Conflicts of Interest

David Miedinger is an employee of the funding organization (Suva). The funder provided support in the form of a project grant that covered salaries for the involved personnel at the Cantonal Hospital Baselland in Liestal as well as expenses for infrastructure and conducting the study, but did not have any role in the study design, data collection and analysis, decision to publish, or preparation of this manuscript. The participation of David Miedinger in this study was independent from the project grant and is covered by the contractual agreement between him and Suva that permits active participation in independently conducted research projects. The other authors have declared that no competing interests exist.

4.5.10 Notice of publication

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4.6 References


Chapter 5: General discussion

Physical activity and aerobic capacity are key factors for promoting health and determine the individual ability to actively participate in the work process. Therefore, it is valuable to monitor activity and fitness levels across different populations. An accurate assessment is required to develop effective intervention strategies with the potential to increase physical activity and improve aerobic capacity. The aim of his doctoral thesis was to objectively measure physical activity and aerobic capacity in patients with chronic obstructive pulmonary disease (COPD) (part I) as well as in healthy employees (part II) and to investigate their relationship with regard to quality of life and reintegration into employment. In this chapter, the main findings and implications for future studies are discussed in relation to the current literature.

In patients with COPD, daily steps and functional aerobic capacity correlated significantly with each other and were independent predictors of quality of life, whereas no relationship was found with moderate-to-high intensity activity (chapter 2). In contrast, in healthy employees high-to-very high intensity leisure-time physical activity (LTPA) was associated with high maximal aerobic capacity (VO$_{2\text{max}}$) (chapter 3). Neither daily steps nor occupational physical activity (OPA) revealed a significant positive association with VO$_{2\text{max}}$. Furthermore, 84% and 75% of subjects fulfilled the global activity recommendations of at least 30 minutes of moderate-to-high intensity activity per day on workdays and non-work days, respectively. VO$_{2\text{max}}$ was higher in sufficiently compared to insufficiently active subjects on workdays, but no significant difference in VO$_{2\text{max}}$ was found on non-work days. When analysing physical activity and aerobic capacity across different occupational groups with low, moderate and high physical work demands, the high-intensity group showed higher levels of OPA than the other groups, while there were no significant differences in LTPA between the groups (chapter 4). VO$_{2\text{max}}$ was considerably higher in men compared to women, but did not differ across groups when stratified for gender. The ratio of physical workload to maximal work capacity was on average one third of VO$_{2\text{max}}$ and increased from the low- to the moderate- and high-intensity group. Women had a higher relative workload than men due to their lower VO$_{2\text{max}}$ when all groups were combined. Multiple linear regressions revealed that physical workload increased by more moderate, high and very high OPA, while it decreased with flex time, longer working hours, higher age and better VO$_{2\text{max}}$.

The present results showed that the relationship of physical activity and aerobic capacity varied between impaired and healthy subjects in terms of activity type and intensity. The discrepancy in intensity could be explained by the fact that patients with chronic lung disease adopt a sedentary lifestyle and get used to the lower level of physical activity, while healthy individuals may require higher-intensity stimuli to achieve health benefits. The diminished daily activity in patients with COPD is confirmed by our results and previous findings. We observed that 88% of patients had a physical activity level (PAL) below 1.70 (sedentary), which is comparable to 78% reported by Watz et al. [1]. Furthermore, steps per day and 6-minute walk distance (6MWD) declined with increasing disease severity, as presented before [2, 3]. In comparison to healthy age-matched counterparts, patients with COPD showed lower walking time and movement intensity during walking as well as higher sitting and lying time [4]. Similarly, time spent in low-to-moderate physical activities and mobility were found to be reduced in patients with COPD [5]. Previous literature reported that health-related quality of life was reduced in inactive patients and correlated with daily steps, 6MWD and PAL [6-8]. However, this is the first study that identified daily steps and 6MWD as independent predictors of quality of life in patients with COPD. These findings and the result that moderate-to-high intensity activity was not associated with aerobic capacity and quality of life suggest that daily steps as a measure of mobility might reflect patient’s functional and health status better than higher-intensity activity.
In contrast, in healthy employees LTPA of at least high-intensity was needed for improving aerobic capacity. This is in accordance with Wilmore & Costill [9] stating that the higher the initial state of fitness, the smaller is the relative improvement for the same volume of training. Subjects with a mean baseline VO\(_{2\text{max}}\) of 40-51 ml/kg/min seemed to require an intensity of at least 45% of oxygen uptake reserve (± 4.7-6.1 metabolic equivalents of task (METs)) to improve VO\(_{2\text{max}}\) [10]. Since VO\(_{2\text{max}}\) values of the majority of our participants were within this range (mean VO\(_{2\text{max}}\): 40 ml/kg/min, SD 10), we could confirm this finding, even if the threshold of 4.7-6.1 METs still falls within moderate intensity, but at the upper limit. An explanation for the finding that VO\(_{2\text{max}}\) was significantly increased by sufficient LTPA on workdays but not on non-work days could be that on workdays employees only have a little time window for exercising outside work, which increases the density of activities. In contrast, on non-work days physical activity may be more unstructured and less efficient because of the extended time availability (lower density). Contrary to expectation, OPA at any intensity was not positively associated with VO\(_{2\text{max}}\). Several reasons may explain this finding. Although OPA is the most performed activity type, it might not be as effective as LTPA, which is planned, structured, relatively short, of high intensity and very efficient. In general, exercises in leisure-time are characterised by the use of large muscle groups in a rhythmic and dynamic way, while working tasks are more intermittent and often involve smaller upper body muscles [11]. Our results are in contrast to previous studies suggesting that OPA and work form could have a significant effect on VO\(_{2\text{max}}\) [12, 13]. The reason that they found positive associations between OPA and VO\(_{2\text{max}}\) might be that they were limited to the use of self-report questionnaires for assessing OPA. There is evidence that subjects may have problems to accurately recall work activity because of its long duration. A Brazilian study confirmed that male and female adults reported unusually high levels of OPA when measured with an activity questionnaire [14]. Therefore, it is likely that the relationship between OPA and VO\(_{2\text{max}}\) is biased in their studies, whereas our findings rely on objective measurements.

When analysing OPA and LTPA across different occupational groups, we observed in accordance with existing knowledge a gradation in OPA between jobs with low, moderate and high physical demands [15, 16]. Surprisingly, no significant differences in LTPA across groups were detected. This suggests that subjects in sedentary occupations did not compensate for their low activity at work during leisure-time. Therefore, when total activity was considered, employees of the moderate- and high-intensity group accumulated more physical activity. Aerobic capacity was significantly increased in the high-intensity group, but did not differ across groups when stratified for gender. This might be explained by the large proportion of males in this group (95%), whose mean VO\(_{2\text{max}}\) was considerably higher than that of females. Regarding physical performance criteria, our results are in line with previous findings expressing physical workload as percentage of VO\(_{2\text{max}}\). Jorgensen et al. [17] proposed that the average acceptable workload limit for an eight-hour workday of mixed physical work was 30-35% of VO\(_{2\text{max}}\), which is consistent with our study (31%). However, they did not account for job- and gender-dependent differences. We found that the upper workload limit was 1.5 times and twice as high in the high-intensity group (44%) compared to the moderate- (29%) and low-intensity group (21%), respectively. Women showed an equal absolute workload as men, but had a 1.5 times higher relative workload due to their lower VO\(_{2\text{max}}\) (37% vs. 26%). This is the first study determining job-specific and gender-related physical performance criteria in healthy employees based on objectively measured workload and work capacity. When reintegrating patients into the work process after phases of sick leave, an individual’s job profile may need to be adjusted. Multiple linear regressions revealed that physical workload can be reduced by introducing flextime or shortening daily working hours. A flexible work design offers the possibility to decide independently when to make breaks and how to plan activity peaks throughout the
day, which might provide a relief of strain. Kelloway & Gottlieb [18] confirmed that work arrangements involving flexibility promoted women’s well-being by increasing perceived control over time and reducing perceived job overload. Another study concluded that a work shift of more than 10 hours should have a lower work intensity than an eight-hour shift, while it could be set at 10% higher for a four-hour shift [19]. A reduction of physical workload is also provided by minimising working tasks in the moderate-to-very high intensity range and by improving aerobic capacity through regular exercise training. In addition, individuals’ age needs to be considered when making work recommendations, as workload should be set to a lower level for older compared to younger subjects. If these adjustments are not sufficient, a change to another job group with a lower physical workload might be indicated requiring professional development or re-training.

5.1 Clinical implications and future perspectives

The results of this thesis could be beneficial for the development of adequate prevention and treatment measures involving exercise in both impaired and healthy subjects. Since physical activity and aerobic capacity are independent risk factors for disease, measuring activity and fitness levels should be an integral part of health assessments. This may help to prevent chronic diseases and disease progression by allowing appropriate education or interventions.

In the therapy of COPD, it is a major goal to improve health-related quality of life by reducing symptoms and improving functional status. Our findings emphasise the importance to participate in pulmonary rehabilitation and to maintain an active lifestyle, such as regular walking to work and in recreation. Referring to the vicious cycle of decline, patients need to remain mobile in daily life to improve aerobic capacity, which in turn may relieve symptoms. As the number of daily steps showed an independent association with 6MWD and quality of life, pulmonary rehabilitation could use this parameter to assess functional and health status in patients with COPD. A concrete plan of action may be that physicians hand out their patients with COPD a low-cost pedometer in order to assess the daily number of steps taken. The target should be set to achieve ≥5000 steps per day according to Tudor-Locke et al. [20]. They found that adults taking <5000 steps per day were more likely to live with chronic diseases and/or disability. As a further approach, patients with COPD might be provided with a mobile app that is able to record steps on a daily basis over a long period of time. The app should include a feedback function for sending weekly reports to patients’ general practitioners. By capturing day-to-day fluctuations, regular monitoring of activity behaviour might enable general practitioners to detect disease worsening at an early stage and to intervene accordingly. However, in routine practice, there is still a deficit in integrating physical activity into daily care and rehabilitation programs. Jochmann et al. [21, 22] found that pulmonary rehabilitation was prescribed to only 5% of patients and only 23% of patients exercised regularly. While treatment of COPD is primarily based on medication, our findings provide strong evidence that regular daily activity and good aerobic capacity might contribute to a considerable improvement of patients’ quality of life. This needs to be confirmed by further studies conducting intervention trials, where subgroups of patients are prospectively assigned to different conditions including drug therapy and exercise training. Medical treatment is not meant to be replaced in COPD, but it may be increasingly supported by other interventions, in particular exercise.

To improve aerobic capacity and health in the working population, it might be recommended for employees to maintain a high level of LTPA on workdays, even if they have high physically-demanding jobs. This could be achieved through the implementation of an attractive and intensive sports program at the workplace during lunch-time or after work. A possible measure for health commissioners of a firm could be to organise aerobic lessons (6.5 METs) or soccer matches (8 METs) during lunch-time for 30
minutes three times a week (Monday, Wednesday and Friday) in accordance with global activity guidelines [23]. In addition, running trainings (7 METs) in preparation for city runs and bike-to-work campaigns (6 METs) could be promoted as part of the occupational health management. However, future studies need to focus on the effect of specific high-intensity leisure-time and sport activities on maximal aerobic capacity, which may help to optimise intervention programs. Since exercise testing is time-intensive and therefore not suitable for public health examinations, the regression equation for estimating $\overline{VO}_2$max developed in this thesis including demographic and SenseWear Mini armband (SWMA) parameters might be used to assess cardiorespiratory fitness in Swiss adult workers. Employees could for example wear the SWMA for one week at regular intervals of six months. This may be beneficial to detect changes in daily activity and resulting aerobic capacity, and to elaborate effective intervention strategies with the potential to prevent chronic diseases in the working population.

The determined activity profiles of different occupational groups are representative for the Swiss working population and might be used for comparisons. For example, as part of a campaign, physical activity of various employees could be measured in order to provide feedback and offer council. The established job-specific and gender-related physical performance criteria may help to develop future guidelines for a safe return to work. Based on these criteria, it can be evaluated whether somebody is able to resume his/her previous work after phases of sick leave. If a patient’s work ability in comparison to population-based values is sufficient to meet the minimum work requirements (lower workload limit) of his/her corresponding job group, then the patient is likely to return to work successfully. If an individual’s job profile needs to be adjusted, various personal and job-related factors should be considered, besides $\overline{VO}_2$max. This is an important finding, since up to now work recommendations were primarily based on individuals’ aerobic capacity. An optimised reintegration process might have the potential to reduce future loss of working hours and related health care costs. To facilitate the implementation of results into clinical practice, the regression equation for predicting physical workload could be used to develop user-friendly calculators (e.g. mobile apps). This would enable different stakeholders (e.g. employees, employers and insurance agencies) to evaluate individuals’ workload in a low effort way. However, future studies need to examine job-specific requirements in more details in order to specify work recommendations, particularly for accident patients. For example, a person with injured legs might be able to perform upper body working tasks, but not those involving lower extremities. Furthermore, $\overline{VO}_2$max represents just one of several components of individuals’ work capacity, and additional abilities including muscle strength (of hands, arms, trunk, back, legs and feet) and coordination should be assessed. For the example above, it may not be possible to perform a 20-meter shuttle run, but to carry out a handgrip strength test with regard to arm-related activities. Moreover, since our analyses were restricted to physical aspects of workload, further research is required to collect data on mental and social work demands. Based on the limitations of the present study, further investigations in subgroups of employees might be valuable to better characterise individual professions. A potential approach could be that 10 employees with the same occupation wear the SWMA in combination with the Firstbeat Bodyguard 2 on a normal workday. The Firstbeat is a user-friendly device for beat-by-beat 24-hour heart rate and heart rate variability measurement, which may provide another perspective for assessing work-related stress levels. The examiner needs to accompany each employee at work during the investigation day in order to directly observe job-specific activities and record their duration with activity logs. By analysing and clustering the measured data, companies could determine job-specific activity patterns of a typical workday (activity peaks, stress levels, transportation, breaks and recovery periods) and generate work requirement profiles for specific working tasks, which may help to optimise return-to-work recommendations.
Regarding the practicability of the applied method for physical activity measurement, both investigated populations (patients with COPD vs. healthy workers) showed a comparable compliance to the SWMA. The rate of missing SWMA data was 10.3% in patients with COPD and 10.1% in Swiss employees. This finding suggests that the SWMA can be comfortably worn in daily routine as well as during everyday work. However, it should not be applied in potentially explosive environments and has not been validated for activities with whole-body vibrations (drivers), respectively under extreme work conditions, such as heat work stations and magnetic fields. When analysing the reasons for incorrect wearing, it can be noticed that patients with COPD more often forgot to put it on after phases of non-wearing, while healthy workers frequently reported no interest, skin irritations or sleep problems. Since patients with COPD were on average 30 years older than the investigated employees, it might be possible that they were more forgetful. Furthermore, it could be hypothesised that healthy individuals are more sensitive for device-related disturbances than chronically ill patients, who are used to a certain degree of disorders. However, this is only hypothetical and needs to be investigated by future studies. Based on the good compliance and high validity for capturing physical activities under free-living conditions [24, 25], the SWMA represents an appropriate tool for measuring daily activity in both impaired and healthy subjects.

5.2 Conclusions and outlook

Overall, we conclude that the relationship between physical activity and aerobic capacity is intensity- and type-specific and needs to be examined individually for different populations. As self-report data may bias the results, objective measurements are required for an accurate analysis. The SWMA represents a convenient instrument for assessing everyday activities in both impaired and healthy subjects. While aerobic capacity was positively associated with daily steps in patients with chronic lung disease, it correlated significantly with high-to-very high intensity LTPA in healthy employees. LTPA was found to be more efficient when performed on workdays, rather than on non-work days. Despite its long duration, OPA did not appear to be predictive for VO$_{2\text{max}}$. These results provide the basis and therefore will be of great value for elaborating preventive strategies to avoid development and progression of chronic diseases in the working population. They suggest to focus on low-intensity daily activity and mobility in chronically ill patients and to create an active, high-intensive leisure-time in healthy full-time workers. By determining the required activity type and intensity for improving functional and health status in specific populations, current activity recommendations can be optimised to ensure maximal efficacy of structured exercise programs. The present findings may be transferred to other chronic conditions, which needs to be investigated by future studies. Regarding physical performance criteria of different occupational groups, relative workload as percentage of VO$_{2\text{max}}$ increased from the low- to the moderate- and high-intensity group and was higher in women compared to men, when all groups were combined. These differences in relative workload need to be accounted for in clinical practice with regard to a safe return to work, particularly for the high-intensity group. The regression equations developed in this thesis for estimating quality of life, aerobic capacity and physical workload provide useful models for daily clinical practice, but need to be further validated. With the generation of big data, pattern recognition and predictive analyses will allow forecasts about the future. The next step would be prescriptive analytics recommending courses of action and showing likely outcomes based on population-derived values. This emerging methodology could be the future trend in healthcare for making diagnoses and return-to-work recommendations, and therefore statistical processes might prospectively replace individual evaluations of patients.
5.3 References


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  PhD thesis: ‘Relationship between physical activity and aerobic capacity in chronic lung disease and in different occupational groups’, Supervisors: Prof. Dr. med. David P. Wolfer, Prof. Dr. med. Jörg D. Leuppi, PD Dr. med. David Miedinger and PD Dr. med. Thomas Dieterle
- 2012: Master of Science ETH in Human Movement Sciences & Sport, ETH Zurich (CH)
  Master thesis: ‘The effects of work and non-work related physical activity on body composition’, Supervisors: Dr. Laura Tomatis and Prof. Dr. med. Jörg D. Leuppi
- 2009: Bachelor of Sciences ETH in Human Movement Sciences & Sport, ETH Zurich (CH)
- 1997 – 2002: High school, Swiss Federal Maturity Type D (Wetzikon, CH)
- 1994 – 1997: Secondary school (Pfäffikon ZH, CH)
- 1988 – 1994: Primary school (Pfäffikon ZH, CH)

Professional experience

- 2012 – 2016: PhD student, ETH Zurich (CH) and University Clinic of Internal Medicine, Cantonal Hospital Baselland (Liestal, CH)
- 2011 – 2012: Research Associate, Clinic of Internal Medicine, University Hospital Basel (CH)
- 2010 – 2011: Internship in prevention and health management as part of a PhD project ‘Relationship between sleep disorders and occupational accidents’, Clinic of Internal Medicine, University Hospital Basel (CH)
- 2009 – 2010: Internship in sports therapy, Psychiatric Clinic Königsfelden (Brugg, CH)

Languages

- German: Native
- English: Fluent (CAE: Certificate in Advanced English)
- Italian: Advanced (DALI: Certificate in Advanced Italian)
- French: Basic
List of publications

Links to website:

Publications, which are relevant for this doctoral thesis, are underlined.


