Review about 3D-body scanning in the LIFE sample and their characteristics in anthropometric, actometric and medical context

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Abstract

Background

The shape of the human body was, is and will be a major point of interest in healthcare: Researchers studied the different types of bodies for years, addressing a variety of different questions, but mostly focusing on classic anthropometric parameters like weight, height and index parameters (e.g. body mass index, waist to hip ratio and waist to height ratio). In the following, this view will be extended by utilizing 3D-body scanner data towards a holistic description of the previously defined body types of Leipzig population and with regard to their relation to activity parameters, physiological parameters, and predisposition to selected diseases.

Data and methods

The LIFE study is a population based cohort study with 10,000 participants (4,766 male and 5,234 female) recruited from the city of Leipzig covering a main age range from 40 to 80 years. The study has been designed to investigate civilization diseases, their risk factors, and potential early onset-markers. In the frame of this study, anthropometry was performed using a 3D-body scanner, and activity data was measured in a smaller subcohort of 2,429 participants using a BodySense Armlet. Anthropometric data were previously utilized to define so-called body types, which collect participants with similar body shapes.

Results

We figured out that most body types are gender-specific, however two body types lack gender-specifics. Moreover, anthropometric and activity parameters show gender-specific differences and change specifically upon ageing: In general, participants are getting smaller, are gaining weight while aging and are losing weight in higher age again. The index parameters are stagnating with growing age, because incremental changes are getting smaller. Also, the participants are less active with increasing age. For physical activity, we were able to confirm a relation between circumference body measures and activity parameters.

In the study anthropometric and activity parameters are evaluated in terms of body type specificity: They reveal similar changes upon ageing as observed in the age strata, but some markedly deviate from these expected developments. We also found health risk body types with potential health issues. Furthermore, we have found that BMI levels are virtually constant in the body types upon ageing, while the activity parameters are steadily decreasing.

The prevalence of a number of relevant diseases like hypertension, hyperlipidaemia, myocardial infarction, angina pectoris, arthrosis and diabetes, but not depression and rheumatism, showed clear associations to the parameters age, BMI, and MET. In general, the risk body types revealed highest prevalence among the body types, partly on gender-specifically differing overall prevalence levels. Paradoxically, obese and 'inactive' body types do not show increased prevalence of myocardial infarctions for men and, especially, for women.

Summary and conclusion

This study has presented a comprehensive and detailed characterization of the anthropometric body types of Leipzig population in the context of ageing, physical activity, and prevalence of major diseases. Understanding body type-associated risk profiles opens new options in diagnostics and therapy. In this sense, anthropometric body typing represents another step towards individualized medicine.

Table of content

Abbreviations

3D Three dimensions	
ACC	American College of Cardiology
AHA	American Heart Association
ATC group C	Section 'C - cardiovascular system' of the Anatomical Therapeutic Chemical Classification System
BMI	Body Mass Index
Bp, RR	Blood pressure
Dia	Diastolic
H	Hours
IPAQ-SF	International Physical Activity Questionnaire - Short Form
IPAQ-LF	International Physical Activity Questionnaire - Long Form
LBM	Lean body mass
LIFE	Leipzig Research Center for Civilization Diseases
MET	Metabolic equivalent
NAKO	German national cohort study
O^2	Oxygen
R^2	Coefficient of determination
SOM	Self organizing map
SWA	SenseWear Pro Armband
Sys	Systolic
WHO	World Health Organization
WHtR	Waist to height Ratio
WTH	Waist to hip ratio

1 Introduction

The human body shape makes up an essential point of interest and attraction in modern society. It is regarded as the key to beauty, health and performance in sports and many other fields. For this reason, research about body shape and body types has been performed for decades and even centuries delivering answers to multitude issues of interest. [15, 66]

Many researchers tried to differentiate body shapes into distinct body types. One of the earliest was W. H. Sheldon. In 1940 he described the body shape and also drew conclusions on character traits related to the body shape. [90] Researchers later tried to find essential parameters for metering the health of people and to find answers on important health issues. They developed several approaches and some of them, particularly the body mass index (BMI), are still in use in medical practice. But all of them reveal minor or major weaknesses. In general, the human organism is too complex to evaluate the health level regarding only a single comprehensive parameter. Such single parameters have been researched in a large number of studies [16, 19, 41, 44, 62, 101], and the results delivered a lot of essential knowledge about these parameters, but were often limited to a very specific question or only a single depending parameter. For a full understanding and later clinical application, we present comprehensive anthropometrical and additional activity parameters to relate body shape to health risk and disease prevalence.

The Leipzig Research Centre for Civilization Diseases (LIFE) study provides deep phenotyping and a large sample size with 10,000 adult participants. It allows exploring rich data on several aspects of health and associated phenotypes, and, in particular in this thesis, to combine data from 3D-body scanners with health and activity related parameters. In this study we have the opportunity to examine various parameters, their mutual relations, and their associations to a number of further aspects such as age and gender related characteristics. [30, 39, 56, 57]

This thesis intends to characterize anthropometric body types of the LIFE ADULT cohort, presenting health related parameters in a detailed and sophisticated way. [38, 39, 56, 62, 68, 72, 91, 101] We will present the anthropometrical and activity related parameters of the cohort and of the body types previously defined. [38] Furthermore we will examine influence factors on the body types and transfer these findings to health issues with regard to prevalence of common but relevant diseases, where body shape types can serve as a novel instrument to regard health problems from a different point of view. Finally, we will summarize our findings as a holistic review of the Leipzig body types. Results presented in this thesis are also described in the article of Frenzel et al.: "**The ageing human body shape"**, focussing on age-related changes of the body measures and the body types in the context of physical activity and disease risk. [Appendix B The ageing human body shape] The manuscript is currently under scientific review.

2 Background

2.1 Anthropometry

In history, several methods were proposed to classify the human body shape into different types. One of the first of such approaches was described in “**The varieties of human physique”** by Sheldon in 1940. [89] This was the first time the term “somatotyping” was formulated to describe the proportions of the human body. Furthermore, the idea of connection between body and temperament, intelligence and moral values has been included in this work. Differentiation is based on the three germ layers: endoderm, mesoderm and ectoderm types. Each somatotype is showing a different domination of these compounds. [68, 89] In 1956, focus of research shifted to cardiometabolic views, e.g. in “**The Degree of Masculine Differentiation of Obesities**” by Vague. [3, 99] The gynoid and the android types of obesity were identified and linked to metabolic diseases like diabetes, hyperlipidaemia, hyperuricemia and cardiovascular diseases. [1, 99] Therefore, the protein anabolism, distribution of fat and level of activity in lipid metabolism were discussed. [99]
The “**Heath and Carter system”** from 1990 classifies body shape types as a mixture of three components: endomorphy (relative fatness), mesomorphy (relative musculoskeletal robustness), and ectomorphy (relative linearity/ slenderness). [22, 37, 68] It complements somatotyping according to Sheldon by using anthropometric measures instead of photoscopic measurements. [17] In “**Somatotyping using 3D anthropometry: a cluster analysis**“ published in 2013**,** Tim Olds validated and extended the Heath and Carter System by using 3D-body scanning for data generation, followed by cluster analysis refining the body types for both men and women. These types differed significantly in mass, BMI and percentage of overweighted and obese participants. [68]

2.1.1 Classic measures

Single anthropometrical parameters were examined for a very long time. Many artists and scientists (Leonardo DaVinci, Albrecht Dürer, etc.) stated the unchangeable rules of body measures to be determinated by laws of nature. [92, 97] The relation of these measures to health issues have become apparent in studies of the last century and were accredited and followed by recent research. [29, 97] In today’s medical practice, ‘classic’ measures are commonly examined comprising weight, height, BMI (Body Mass Index), waist circumference, WHR (Waist to Hip Ratio), Waist to Height Ratio (WHtR) and blood pressure, to get an overview about the patient’s constitution. [7, 11, 41, 45, 63, 79, 100]

Determinants and changes in these classic measures have been investigated in numerous studies providing fundamental medical knowledge. [1, 3, 29, 44] For example, people are usually gaining weight until an age of 60 to 65 years, and are subsequently losing weight for several reasons. Aspects like bad dental status, dysgeusia, dysphagia, diarrhea, chronic disease, depression, dementia, social isolation, drugs or other reasons can influence the loss of weight. [60] Another example is growth, which is usually completed between 19 and 24 years of age. From this time on, people are losing up to 8 cm in height, which can be caused by degeneration of the intervertebral discs, distortion of the vertebral column or chronic diseases like osteoporosis associated with degeneration of bone tissue. [51, 60]

2.1.2 Physiological indices

Beside broad utilization of the classic measures, aggregated physiological indices have been developed to provide accessible and robust information about complex physiological conditions like fat distribution, underweight and overweight associated with health issues. [7, 11, 20]

One of them is the body mass index (BMI), which is the current "gold standard" in body grading. It is defined as body weight in kilograms divided by squared body height in meters. [1, 101] The BMI was developed by the Belgian mathematician Adolphe Quetelet in 1832, but the broad utilization for medical purposes started in 1972 when Ancel Keys published the article "Indices of relative weight and obesity". [11, 49, 74, 101] At first, BMI was used as an economic tool for health insurance, but later in the 1980's also by the WHO to classify obesity. [16, 44, 101] Recent and most commonly used definition of BMI categories were stated in the report of WHO consultation on obesity in June 1997 in Geneva. [69] Although, it is the most popular tool, the BMI is not suitable to supply information about fat distribution and does not regard body surface, age, or muscle to fat ratio. [1, 101] Eight categories from "very severe underweight" (score < 15) to "obese class III" (score > 40) cover characteristics from thin to thick. [1, 101] The BMI related mortality curve follows a u-curve with lowest death rates of around a BMI of 20, and high risk for extremely low and high values. [36, 100]

Another index is the waist to hip circumference ratio (WHR), which is calculated as the circumference of the waist divided by the circumference of the hip. It was introduced as an aesthetic benchmark by Devendra Singh in 1993, but it also provides information about fat distribution and fertility. [41, 99] The WHR reveals gender associated differences in fat distribution commonly known as the apple and pear types, which are corresponding to the android and gynoid types defined by Vague. According to this, the apple type is more prevalent in men, while the pear type is more prevalent in women. [68, 99] Apple type patients have a higher risk to suffer from diabetes, gout, stroke, myocardial infarction,

arteriosclerosis or other metabolic diseases, because visceral fat introduces pathological changes in fat metabolism. [3, 99, 103] On the contrary, subcutaneous fat stored around the thigh and the buttock associates with the pear type and is less active in the fat metabolism. [45, 49, 103] The apple type is defined by WHR > 0.8 in women and WHR > 0.9 in men and implies significantly higher risk of health issues. [41, 84, 99] Despite WHR delivers useful risk assessment, it is limited especially with regard to patients that lose weight in the course of health improvement programs, because both hip and waist girth decrease and leave WHR virtually unchanged. Also a systematic shift can be observed during aging, where the majority of individuals attain an apple body type. [41, 99]
Finally, the waist circumference to height ratio (WHtR) is defined as the circumference of the waist divided by body height, and being an effective global indicator for health risk regarding proportion of fat in different groups of age. [7–10, 61] Ashwell and Hsieh are showing advantages of the WHtR in their paper '**Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity**'. In essence, WHtR is more sensitive than BMI as an early indicator for health risks. Particularly, a WHtR of 0.5 or more indicates an increased risk for hypertension, diabetes, and dyslipidaemia. [8, 9] Furthermore, WHtR is also suited for assessing children's and adolescents' health. [9, 10] One drawback of WHtR is the varying thresholds depending on age: People younger than 40 have lower health risk with values below 0.5, while people older than 50 are showing lower risk with WHtR values up to 0.6. [8, 10]

2.1.3 Usage of 3D-body scanners in medical applications

For several years, 3D-body scanning has been in use in various commercial fields like apparel design and ergonomics. Its use for medical purpose is increasing as well, e.g. in cosmetic and reconstructive surgery, and recently in medical and health research to study anthropometry because of high accuracy, reproducible measure, and easy and non-invasive generation of information. [57] These features of 3D-body scanning are ideal for large scale epidemiological surveys, which will deliver improvement of current anthropometric standards and potentially, in long term, replace of manual anthropometry. [38, 57, 68, 91]

2.2 Physiological parameters

A set of physiological parameters is used as standard examination to represent the activity level or physiological traits of a patient or subject. Contrary to anthropometric parameters, these parameters are more variable and underlie strong short-term changes. Steady physiological changes or diseases disturb the homeostasis, and directly cause ongoing changes in these parameters. [12, 21, 59, 83]

2.2.1 Measurement of physical activity

Physical activity is usually measured in terms of a participant's energy consumption, which is depending on certain physiological parameters such as exercise duration and intensity. [12, 18, 33, 64] Therefore, sole consideration of energy consumption cannot give any information about the kind or volume of physical activity. [12, 85] The body constitution also influences energy consumption, resulting in a positive correlation between body mass and energy consumption. [30] Measurement of physical activity consequently has to adjust for the relation of energy consumption and body mass: The metabolic equivalent estimates energy consumption by measuring oxygen uptake based on the amount of energy provided per liter of oxygen. [30] The metabolic equivalent (MET) is a simple and practical approach to measure the energy cost of physical activity. [24, 42, 59] One MET is defined as the amount of oxygen consumed while sitting at total rest and is equal to 3.5 ml O_2 per kg body weight and minute. [42, 83] There are reference MET values for various activities assigned to different intensity categories: low intensity (<3 MET), moderate intensity (3-6 MET), vigorous / high intensity (>6 MET), and a very high intensity (>9 MET). For example, jogging with a speed of 9 km/h corresponds to a MET value of 8.8. Another example is walking a speed of 3 km/h, which is indicated by a MET value of 1.8, and by a MET value of 5.3 at 7 km/h. [24, 30] MET is often used to describe the functional capacity (aerobic power) of an individual and to improve training effectiveness, however the approach has limitations. [42, 83] Very important is the dependency of the MET values on the level of intensity in which the certain activity is performed. Another point is the constitution of a person, which causes different resting metabolism, e.g., taller and more athletic people versus those with the same body mass but higher body fat and lower lean body mass (LBM). [42, 59, 83] Further limitations of the MET system are differing effectiveness and also environmental conditions, interfering with the level of intensity. [42] Moreover, there are pathological factors which influence the metabolism, such as endocrinological disorders (e.g. hypothyroidism, etc.) and diseases of the cardiovascular and respiratory system. [42, 75, 81]

Nowadays, tracking physical activity is becoming more popular. Devices like Apple Watch, Fitbit and others provide easy usage and the opportunity to share and to compare performances with the community. Many articles describe the association of physical activity and aerobic fitness on the one hand, and morbidities like cardiovascular, musculoskeletal and cognitive diseases on the other hand. [21] Social Health organizations like American Heart Association (AHA) and the American College of Cardiology (ACC) Foundation promote daily physical activity to maintain health, recommending at least 150 minutes per week in moderate or higher intensity physical activity with special attention to the combination of improving aerobic fitness and muscle strengthening. [2, 24, 30, 65, 83, 102] Older people are often limited in their physical activities because of chronic diseases or other circumstances. Adapted recommendations addressing this group are also available. [21]

In this thesis, we also utilize and describe the number of steps taken per day as a simple measurement for physical activity. Steps can be considered as unit of walking which is an activity of low or moderate intensity depending on the walking speed. We can link the number of steps to the prevalence of disease, level of fitness or further health risks. An often recommended criterion for maintaining health is to walk 10,000 steps per day, corresponding to a walking distance of 5 to 8 kilometers depending on the length of each step. [21, 65, 81, 95, 98]

2.2.2 Blood pressure

Another common health parameter is blood pressure, which provides physiological information about the cardiovascular system and which is influenced by condition, weight, and height. [4, 105] High blood pressure is a main risk factor for other cardiovascular diseases such as arteriosclerosis, myocardial infarction and stroke [5, 22, 82] Measurement of blood pressure began in the 18th century by the English physiologist Stephan Hales, who observed the liquid column after cutting horse vessels. The current gold standard of non-invasive measurement of blood pressure was invented by the Italian Scipione Riva-Rocci in 1896, who described how to stop the blood flow by a cuff on the upper arm and measure pressure with a mercury sphygmomanometer which shows pressure by a mercury column. [6, 25] In 1905, Nikolai Sergejev Korotkoff improved the method by auscultating specific sound of swirls in the vessels by using a stethoscope. [6] The reference value of a healthy blood pressure is considered as 120/80 mmHg, values of 140/90 mmHg or more are indicators for a hypertension. [52, 104, 105] Definition of these reference values and the awareness of a relation between blood pressure and diseases was a discussion lasting more than 100 years mainly in the 20th century. [6, 33] Blood pressure usually increases with increasing age, because elasticity of the vessels degrades causing a lower range of blood pressure values. [4, 13, 31] Thereby, mainly systolic pressure increases, resulting in isolated systolic hypertension.

3 Data and Methods

3.1 LIFE – the Leipzig population study

The data utilized in this thesis has been collected in the context of the Leipzig Research Centre for Civilization Diseases (LIFE), a population based cohort study with baseline examination of 10,000 randomly selected participants. [56, Appendix B The ageing human body shape] The assessments have been performed at the Medical Faculty of the Leipzig University, the Leipzig Heart Centre, and the Max Planck Institute for Human Cognitive and Brain Sciences Leipzig. The study covers a main age range from 40 to 80 years with particularly deep phenotyping in participants older than 60 years. [56] The baseline examination started in August 2011 and was completed in November 2014. [56]

All participants underwent an extensive core assessment program (5-6 h) focusing on prevalence, early onset markers, genetic predispositions, and the role of lifestyle factors of major civilization diseases. [56] One part of the baseline program was 3D-body scanning to obtain reliable and comprehensive anthropometrical characterization of the participants. [38]

The total sample size of the LIFE study is 10,000 (see Table 1 and [56] for details). The cohort comprises 4,766 men and 5,234 women. For each participant, comprehensive information is available, for example general characteristics such as age, social status, and clinical background. Additionally, data on 3D-body scanning is available for 8,499 participants [38], and data on physical activity for 2,429 subjects [39, 56]. Criteria for selection and filtering will be described in the next chapters. Furthermore, disease history of the participants has been assessed via different questionnaires. [56] The data of disease histories presented in this thesis are nearly complete (see Table 1).

Please note that the age group from 18 to 39 years are significantly underrepresented and biased towards obese participants by selection criteria of this sub-cohort [56]. Therefore, this group we will excluded from analyses.

Table 1 Data availability

	Total	Male	Female
Study population	10,000	4,766	5,234
18 - 39	513	258	255
40 - 49	2,658	1,208	1,450
50 - 59	2,290	1,050	1,240
60 - 69	2,543	1,208	1,335
>70	1,990	1,039	951
3D-body scanning	8,499	4,126	4,373
Actometry	2,429	1,110	1,319
Disease history[1]	> 9000		

[1]data not complete for all diseases

3.2 Anthropometry using 3D-body scanning

For the purpose of 3D-body scanning a VITUS SMART XXL body scanner with integrated pedestal and scale was used. [17, 38, 40, Appendix B The ageing human body shape] It consists of four pillars with laser devices covering a scanning volume of 2.1 m in height, 1 m in depth and 1.2 m in width. The measuring process is based on optical triangulation with laser light sent by eight laser sensors. [17, 38, 40] The process of a single measurement is completed in less than 12 seconds. The scanner provides a 360 degree spectrum with a maximal girth error of 1mm. It is suited for population studies fulfilling the DIN EN ISO 20685 standard. [17, 28, 38, 71, 91]

The measuring process follows a standardized procedure. [96] We considered 136 measurements including 97 (linear) lengths and distances, 36 (curved) girths, 2 angles, and the weight. In addition, we included three aggregated characteristics: body mass index (BMI), waist to hip ratio (WHR) and waist circumference to height ratio (WHtR). [38, 39]

3.3 Definition of meta-measures and body types

3D-body scanning data of the LIFE study population was recently analyzed using self-organizing maps (SOMs), a machine learning approach which clusters the 136 single body measurements into 13 meta-measures. These meta-measures were arisen to be robust with regard to selection and variation of cohort size. They enable characterization of diversity of body shapes in a reliable and dimensionally reduced way. [38] The meta-measures were then used to stratify the cohort into body types, which were also validated with regard to cohort size. [14, 38] It could be shown, that the number of detectable body types scale with sample number. Rare body types may be observable in future large-scale studies. [38, 58] We found two body types which collect larger fractions of both male and female participants (B1 and B2), representing body shapes almost lacking gender-specifics. Six body types were showed to be nearly exclusively female-specific (F1-F6), while seven body types showed to be male-specific (M1-M7). [38, 57] These body types were first described in "**Novel anthropometry based on 3D-bodyscans applied to a large population based cohort**" by Löffler-Wirth et al. in 2016.

In addition to the gender-specifics, the incidence of body types is age-dependent. For each body type we therefore defined a reference group representing the age-adjusted and gender-specific mean over all participants regardless of their body type. Age-adjustment considers a window around the mean age of the body type plus/minus five years to ensure a sufficient number of participants in the reference groups. This way, the approach opens possibility to statistically compare different mean body type ages. In particular, we applied Wilcoxon rank-sum test to identify significantly differential characteristics of a body type in comparison to its reference group.

The two gender-unspecific body types B1 and B2 contain considerable numbers of both female and male participants. For our analyses, we divided these body types into female and male subsets to avoid a gender-driven bias of the results.

3.4 Methods for measuring the physical activity

Several direct and indirect methods to measure physical activity have been published within the last years. [12, 30] The gold standard for measuring energy expenditure is the metabolic cart CO_2 machine (ergospirometer), based on the fact that energy consumption is linked to a defined uptake of oxygen, and accompanied by disposal of carbon dioxide. [42, 55] However, this method is virtually restricted to a laboratory environment. For the LIFE study, a method well established, moderate in costs, highly accurate, and suited for large population studies has been chosen: The Body SenseWear Pro Armband (SWA), which was worn by a subcohort of almost 2,500 participants (Table 1). [23, 27, 55, 75] Additionally, information about the physical activity has been assessed using the IPAQ questionnaire [24] for mainly all LIFE participants.

3.4.1 Body SenseWear Pro Armband

Movement and acceleration sensors have strongly gained popularity in the last years due to the opportunity of obtaining valid information from a small and robust device. However, those gadgets have been rarely used in large scale cohort studies as they are more expensive and cause logistical problems compared to widely used questionnaires such as IPAQ. In LIFE, both approaches were applied in a subcohort.

The SenseWear Pro Armband (SWA, Bodymedia, Inc., Pittsburgh) is a multi-sensor tool with two-axis-accelerometer, heat flux sensor, galvanic skin response sensor, skin temperature sensor, a near body ambient temperature sensor, and heart rate detection using a chest strap. [75] Blood pressure has to be measured separately [30, 55, 64]. After parameterization in terms of age, gender, height and weight, the SenseWear Professional Software delivers multiple inferred activity data such as active energy expenditure (AEE), number of steps, energy consumption in terms of metabolic equivalent (MET), and time spent in low (<3 MET), moderate (3-6 MET) and vigorous intense activity (≥6 MET). [30, 55] For this, different sensor data are evaluated and combined. For example, total calories consumed in low intensity activity is computed by heat loss recorded by the calibrated heat flux sensor and high level activity periods are detected by the accelerometer in combination with heart rate detection. [55]

Formal requirements for reliable information about the physical exercise of each participant are defined as follows: The SWA has to be used on eight or more days, including at least four weekdays and one weekend day. [30, 55, 64, 85] Additionally, we only considered days with a sufficient wearing time of at least 18 hours on weekdays, or at least 20 hours on weekend days. Under these conditions, the SWA delivered valid and reliable data of 2,429 participants (Table 1) as proven by several validation tests. [55, 64, 81, 85, 95]

Limitations of the SWA are due to situations wearing the SWA is not possible, for example while swimming and other activities in or near water. [30] The abovementioned logistic problems are due to the limited number of SWA available in the study centers combined with the long wearing duration for each participant.

In summary, utilization of SWA provides reliable and high quality data with lower costs than laboratory methods and more objective information than questionnaires. [20, 21, 38, 42]

3.4.2 IPAQ

The International Physical Activity Questionnaire (IPAQ) was developed in 1998 to provide reliable information about physical activity for large cohorts independent of residence and ethnicity. [24] Since 2000, many validation studies followed, proving acceptable reliability and usability for international practice. [50] The IPAQ eventually became the most widely used questionnaire for physical activity, and is currently available in two versions: the long form (IPAQ-LF, with 31 items) and the short form (IPAQ-SF, 9 items). [23, 50] In LIFE, the short form has been used, assessing information about the minutes per week spent in four defined intensity levels (sitting, walking, moderate intensity, and vigorous intensity) providing the estimated MET energy expenditure. [24, 30, 42, 50]

3.4.3 Comparison of IPAQ and SWA

The study “**Physical Activity Assessment – a Comparison between IPAQ-SF and SenseWear Pro Armband**” has been performed by Gaede-Illig et al. using data of the LIFE study to compare the subjective and objective instruments to measure physical activity. [30] For this, 434 participants (202 men and 232 women in the age of 18-78) answered a questionnaire about their physical activity (IPAQ-SF) and used the SWA. To compare both instruments, intra-class correlations and spearman`s rank correlations with the objectively measured active energy expenditure have been calculated, and Bland-Altman analyses have been performed. [30] The major finding was, that subjective activity values derived from

IPAQ were significantly higher than corresponding objective SWA values, indicating that participants are overestimating their physical activity. [30] This study also showed, that parallel use of subjective and objective methods is recommended to judge the difference between self-perception and real activity. [30]

3.5 Units

The following units are used for the given parameters if different units are not shown.

Table 2 Units

Parameter	Unit
age	years
height, girth	cm
weight	kg
BMI	kg/m^2
time	hours
blood pressure	mmHG
energy consumption	kcal

4 General characterization of the study population

This chapter will present classic, anthropometric, and actometric characteristics of the study population and will examine relations between physical activity and the body measures.

4.1 Anthropometric parameters vary upon aging

Age is virtually uniformly distributed in the LIFE population in the targeted range from 40 to 80 years (See Table 1). In the following figures, selected characteristics will be presented in terms of violin plots. [Appendix B The ageing human body shape] For the parameter weight, we see the trivial fact that men are generally heavier than women, and that weight increases with increasing age as expected, with a maximum at about 50 years followed by slight decline (Figure 1 a). Distribution of weight, as well as the other measures presented, follows a normal distribution. It is to be considered that multiple outlier participants with very high levels of weight have been observed. The median values of the respective age groups are below the overall gender-specific mean values, which indicate a systematic shift towards heavy outliners. These findings are in line with previous knowledge. [32, 86]

Furthermore men are taller than women, and body height is steadily decreasing in the age range of the study (Figure 1 b), confirming the general loss of height in the course of aging caused by e.g. degeneration of the intervertebral disks. [43, 47, 86, 86]

The body mass index (BMI) is defined as the ratio of weight in kilograms and height in meters squared, and it is one of the most used risk indicators for heart and cardiovascular diseases. [11, 44] As result of increasing weight until an age of 50 years and decreasing body height, we found the tendency of an increasing BMI in this age range. In general, men show higher BMI values than women caused by gender-specific weight and height differences. Different from the previous parameters weight and height, there is no clear trend for older participants: Age dependent on loss of weight and body height compensates each other resulting in virtually constant BMI for participants older than 60 years (Figure 1c).

Figure 1 Basic anthropometric characteristics of the study population in terms of violin plots stratified by age and gender. The dashed horizontal lines refer to the overall median value of male and female participants, respectively. Panel d: Distribution of participants classified as under-weight (BMI<18.5, see also Table 3), normal weight (18.5≤BMI<25), over-weight (25≤BMI<30), and obese (BMI≥30) according to WHO classification. [69]

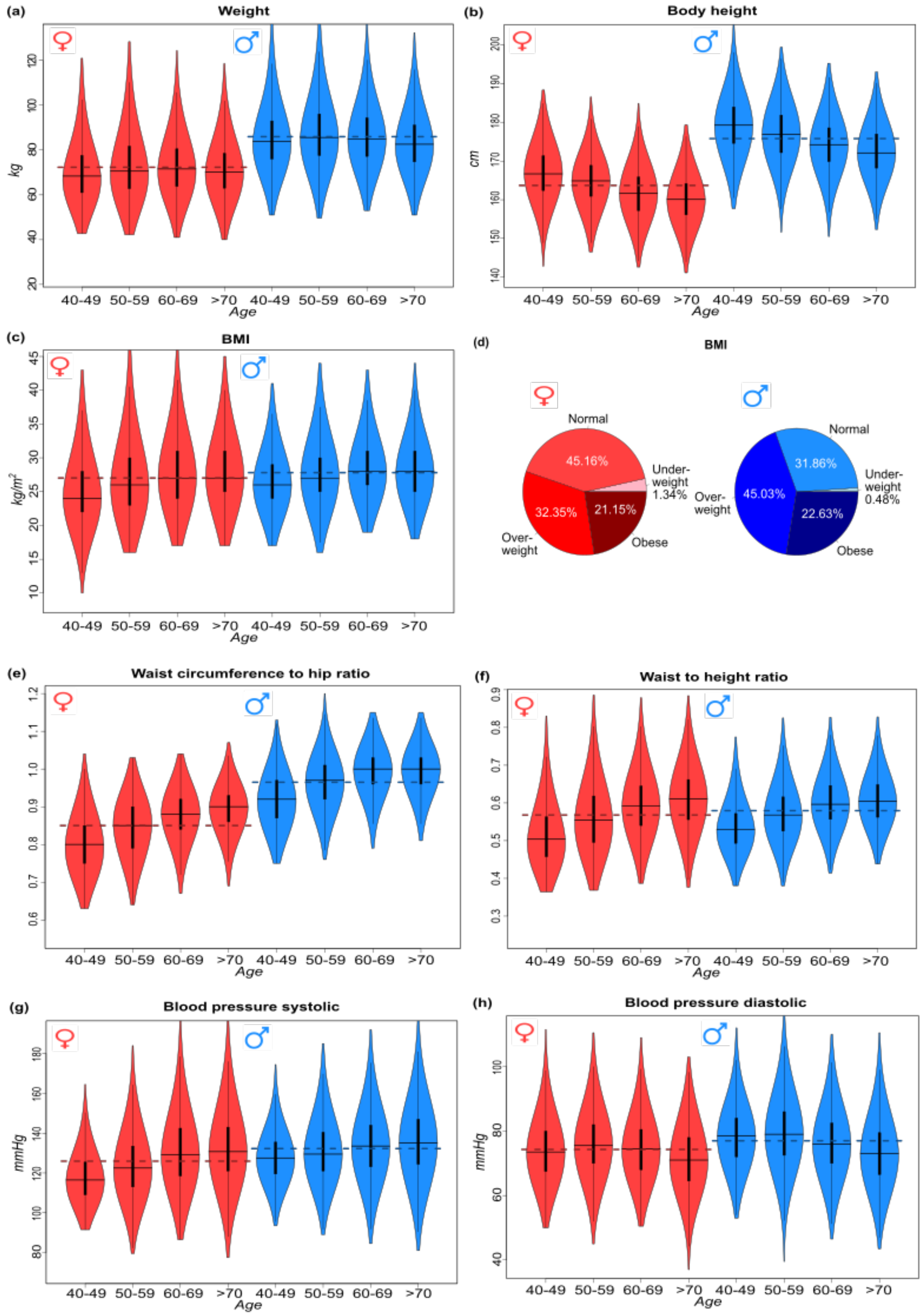


Table 3 Classification of the study population according BMI categories defined by WHO [69]

# participants	Underweight (BMI < 18.5)	Normal weight (18.5≤ BMI < 25)	Overweight (25≤ BMI < 30)	Obesity (30 ≤ BMI)
female	68 (1.3%)	2289 (45.2%)	1640 (32.4%)	1072 (21.1%)
male	22 (0.5%)	1471 (31.9%)	2079 (45.0%)	1045 (22.6%)

Notably, the majority of participants of the LIFE study is overweight or obese, only few are in the category of underweight (See Figure 1 d and Table 1), which is similar to recent data. [32, 43, 70, 84, 89] Two thirds of men and 53% of women have a BMI exceeding medical recommendation (BMI> 25), which is associated with an increased risk of suffering from disease.

The waist-to-hip-ratio (WHR) is the quotient of waist circumference and hip girth (Figure 1e). The popular classification of apple and pear types utilizes WHR and addresses the distribution of fat which comes along with different health risks. WHR implies gender-specific thresholds, as male participants in general have a higher WHR.

WHR values are increasing with age, particularly until an age of 60 to 69, followed by lower increase. Men's average WHR is located at intermediate to high risk level, women's average WHR is at a high health risk level in this study. [38, 91] Based on these findings we can conclude that a major part of the participants is indicated by unhealthy fat distribution as seen by WHR.

WHtR is another index parameter and defined as the ratio of waist circumference and body height. [8, 9, 20] WHtR is increasing in higher age groups, and the male average WHtR is slightly exceeding the female one. It is to be noticed that women have lower WHtR values in younger age and a higher WHtR in older age compared to men. Reference values of WHtR are both gender- and age-specific. In the LIFE study population we found that about half of the participants older than 60 years showed health threatening values of WHtR (> 0.6), the reference value for people older than 50 years. [9, 20]

The parameters and indices presented above are all related to the participants' body shape. Our results correspond to recent knowledge, which means that a major part of the participants show health threatening body measures. Deducing from index parameters BMI, WHR and WHtR, participants are showing too high weight levels compared to their height, higher health risk due to their fat distribution and/or as a consequence of concentration of fat around their waist in relation to their height. Most of the health threatening values are accumulated in the older age groups.

The following will present data on blood pressure which is the parameter most often applied to reflect vital body functions with crucial impact on health and disease (Figure 1 g & h). [13, 35, 104] In particular, we will examine systolic left and diastolic right blood pressure separately.
Systolic blood pressure is increasing in higher age groups. Men had a higher average blood pressure than women, but the increase of blood pressure during aging is higher for women. Notably, variability of systolic blood pressure increases during lifetime (see increasing violin lengths in Figure 1 g). Until age range between 50 and 59, more than 75% of all participants fell below the critical level of 140 mmHg. In turn, more than 50% of the participants showed values higher than the normal reference indicated by 120/80 mmHg. [52, 104, 105]

The average diastolic blood pressure of men is higher than the one women obtain, with more than 75% of participants below the critical level (RR_{dia}<90mmHg). Diastolic blood pressure's variability is higher than systolic blood pressure's and it is usually increasing until the age between 50 and 59. Importantly, and contrary to systolic blood pressure, diastolic blood pressure decreases during further aging. This is reflected by a basically lower pressure of the whole cardiovascular system. Various reasons are responsible for these processes, e.g. lower levels of intravascular volume or changes of the structure of the vascular wall. [13, 31, 35] A total of about 1,300 participants stated to take medication targeting cardiovascular system (ATC group C), which is a bias to the blood pressure data. Consequently, there is a smaller part of participants with a too high blood pressure (>140 mmHg systolic) than expected, as well as participants with exceeding high blood pressure despite antihypertensive medication. Participants in this subgroup putatively suffer from undiagnosed hypertension or are being treated insufficiently.

The parameter blood pressure concludes our selection of classic and anthropometric measurements presented in this thesis. Throughout all these parameters, we found potential health risks predominantly in older age groups. Many parameters are indicated by a large fraction of participants with critical values, which is in line with percentages provided by recent health studies in Germany. [78] Contrary, younger participants are indicated by values which are associated with a healthy body. The characteristics presented here are almost identical in both genders. Nevertheless, but probably most importantly, a clear dependence of the parameters on the aging process can be observed.

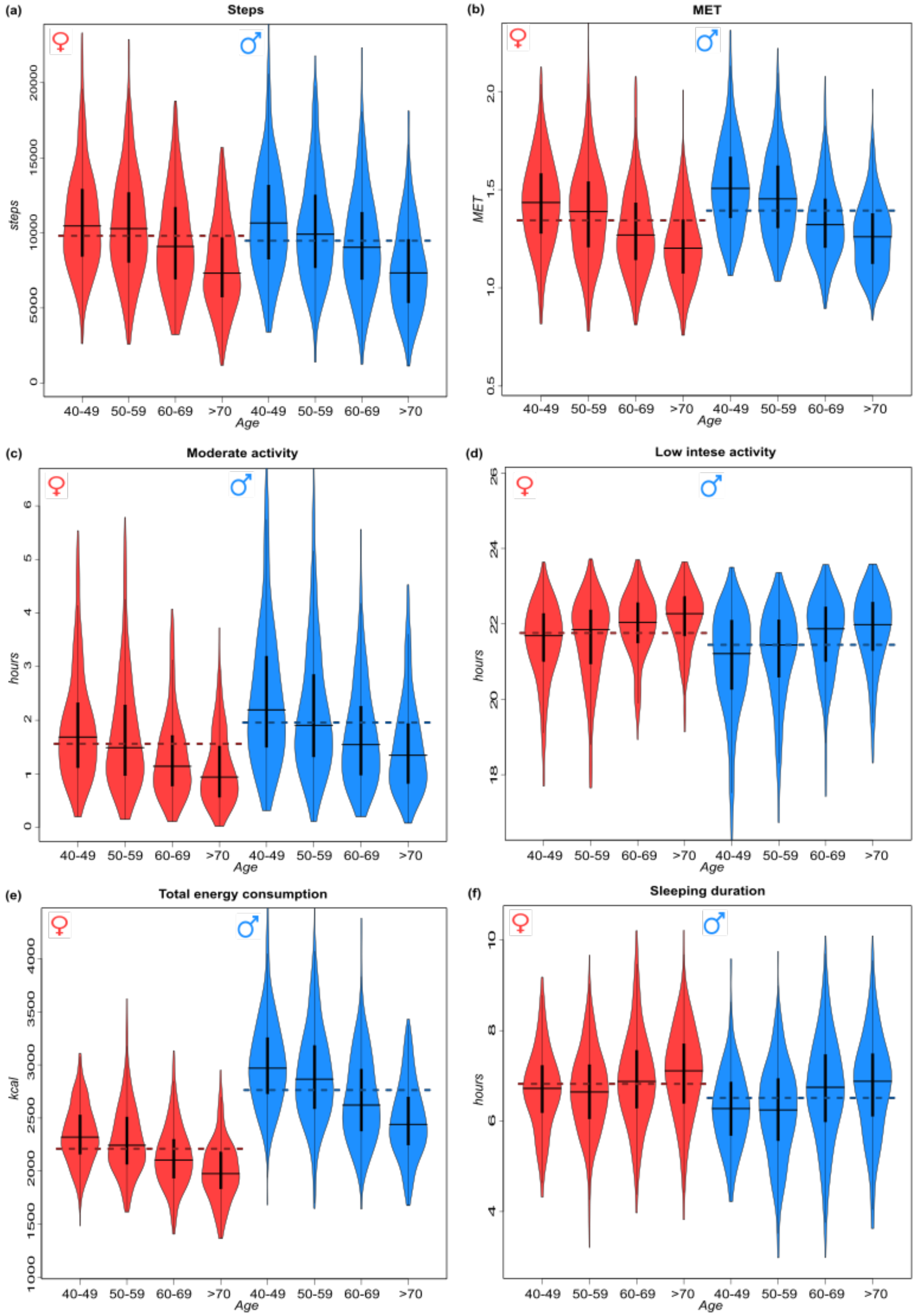
4.2 Activity level decreases with age

This section will present selected activity parameters which were obtained for the study population using the SenseWear Pro Armband: Steps, MET, time spent in moderate and low intensity, total energy consumption and sleeping duration. The analysis of these data is restricted to the participants with appropriate wearing time and days as described in the Data and Methods section.

The number of steps is currently of public interest due to the broad availability of fitness tracking devices. It reflects countable information of activity, which is easily available, convenient and individualized. On average, women show a slightly higher number of steps than men. However, both genders show a very similar decrease during aging, indicating less physically active lifestyle of older participants (Figure 2 a). Most participants fall below the reference value of 10,000 steps per day, which is regarded as the level of activity to maintain health and to support the cardiovascular system. [53, 98] Notably, the variability of the number of steps walked is decreasing in older age, which means that there are less participants with particularly high or low numbers of steps.

The number of steps walked is related to the level of MET, the gold standard of quantifying physical activity, but MET covers a broader range of activities than the number of steps and potentially adds valuable information of the participants' individual activity level. In the LIFE study population, MET is steadily declining with increasing ages, very similar to the number of steps (Figure 2 b). Men are showing a higher mean MET than women, which confirms the fact that a higher part of men is working in a job with higher amount of physical activity.

Figure 2 Activity parameters of the study population in terms of violin plots stratified by age and gender. The dashed horizontal lines refer to the overall median value of male and female participants, respectively.



Next we will discuss the time participants have spent in moderate and low intensity activities (hours per day), which are inversely related parameters: The time spent in low, moderate and high intensity activities sum up to 24 hours of a full day. Data on high level activity are not presented in this paper because the participants spent on average 30 minutes per day in this category, which is not sufficient for data analysis. For moderate intensity activities, we found steadily decreasing times accompanied by decreasing variability in both genders (Figure 2 c). Men are spending more time doing moderately intense activities than women, and both genders showed a strong decline within the age groups of 50-59 and 60-69. This can possibly be attributed to a change of the physical activity accompanying retirement from work. Time spent in low intensity activities shows the inverse characteristics and increases with age (Figure 2 d). Taking 24h as a reference, most of the participants spent between 80% and 90% of their time in low intense activities including sleeping time. The variability of both times in low and in moderate intensity activities is decreases with age, reflecting that the difference between active and non-active older participants is smaller than in younger participants groups. One reason could be that less frequent regular sports activities are lowering the upper limit of activity levels, whereas the consistent lower limit in all ages is due to missing moderately intense activities at all.

The total energy consumption represents aggregated information complementary to the previous parameters, because it relates to individual parameters and depends on multiple factors such as age, body weight, and gender of the participant. Difference of mean energy consumption per day in women and men is about 500 kcal, and it continuously decreases along the aging process (Figure 2 e), which is in line with common knowledge. [12, 30] Like in the parameters before, similar development of total energy consumption were observed.

As stated above, sleeping duration is also part of the time spent in low intense activities, and it consequently follows a very similar progression. Women sleep, on the average, more than men (Figure 2 f). Participants between 50 and 59 years showed the fewest sleeping hours, as sleeping duration increases with further age. Noteworthy is the high range from “long-sleepers” (> 8h) to “short sleepers” (<6h) in all age groups, and the strong increase of sleeping hours between the age of 50-59 years and 60-69 years among men which is probably caused due to the retirement from work as discussed above.

A general observation in all parameters were the higher physical activity up to an age of about 60, and lower activities in further age. In particular, step number, MET, moderate intensity activities and energy consumption showed higher values in the younger age groups, whereas low intensity activities and sleeping duration was present with higher values among the older participants. Another finding was the abrupt decrease of activity after the retirement from work. Differences between genders are negligible except for the gender-specific shift of energy consumption.

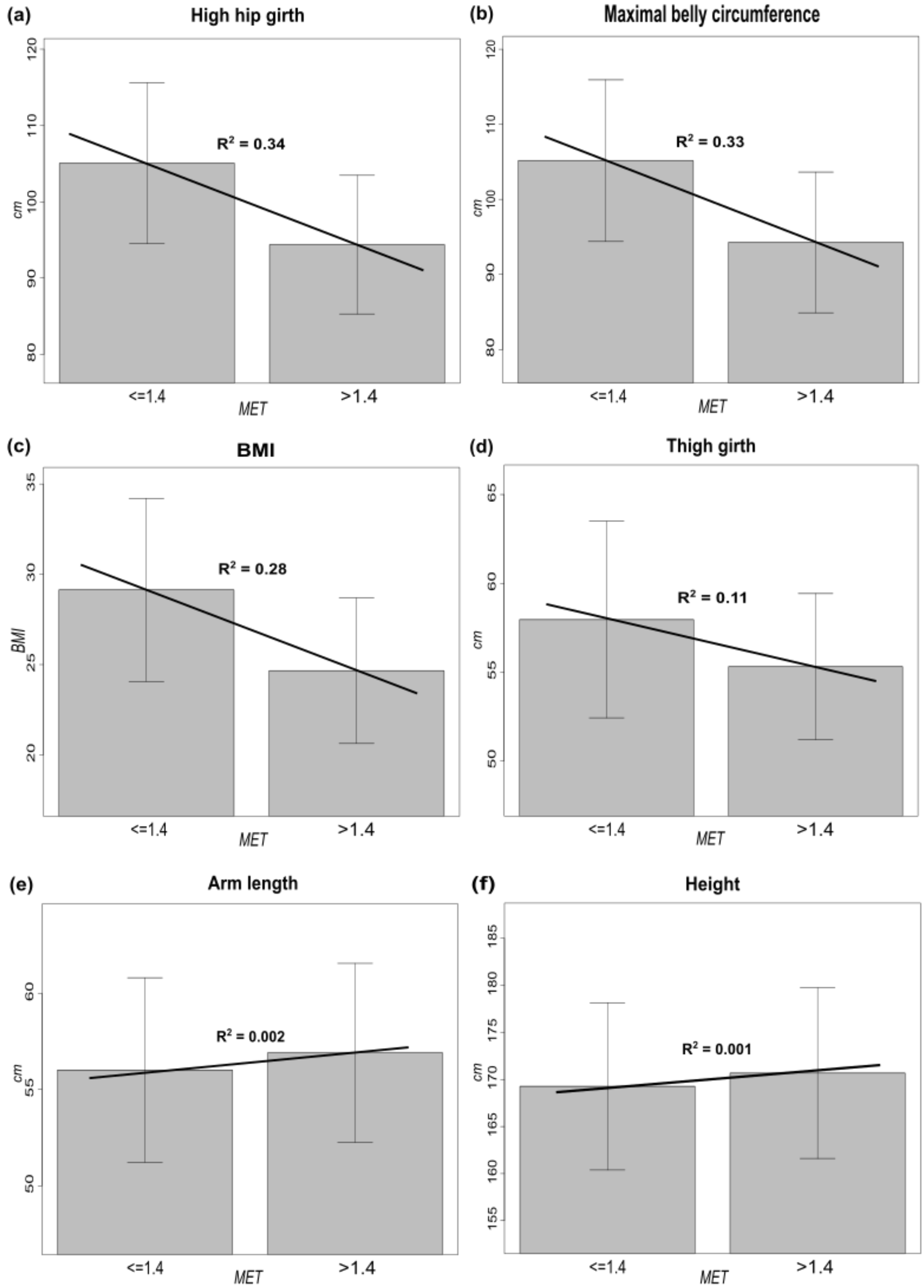
4.3 Body measures associated with activity parameters

Before assessing relations between body types and physical activity, relations between individual body measures and physical activity were evaluated. Out of the 150 body measures provided by 3D-body scanning, six measures have been selected for illustration (Figure 3). Thereby, body measures of less and more active participants have been compared using overall median MET as cutoff. Additionally, the coefficient of regression (R^2) for linear regression model of MET and the body measure were provided through all participants.

For example, hip girth, belly circumference and BMI reveal strong relations to MET (Figure 3 a, b & c), while relations between thigh girth and MET are less pronounced (Figure 3 d). In general, strong relations between MET and most circumference measures of the body were observed. (Appendix A Regression analysis of body measures towards MET.) Length measures and angles showed only minor relations to MET: Arm length and body height were positively related to MET (Figure 3 e and f). However, this effect was weak compared to BMI and circumference measures (see R^2 values in Figure 3).

With these findings about relations between body measures and activity parameters, we will proceed to the question, how activity levels and the body types of the participants relate each to another. The relation of all body measures to MET is shown in the appendix. (Appendix A Regression analysis of body measures towards MET.)

Figure 3 Relation of selected body measures to MET: Bar plots represent values of body measures for less and more active participants (MET <=1.4 and >1.4, respectively). R² is given for linear models over all participants.



5 Description of the body types

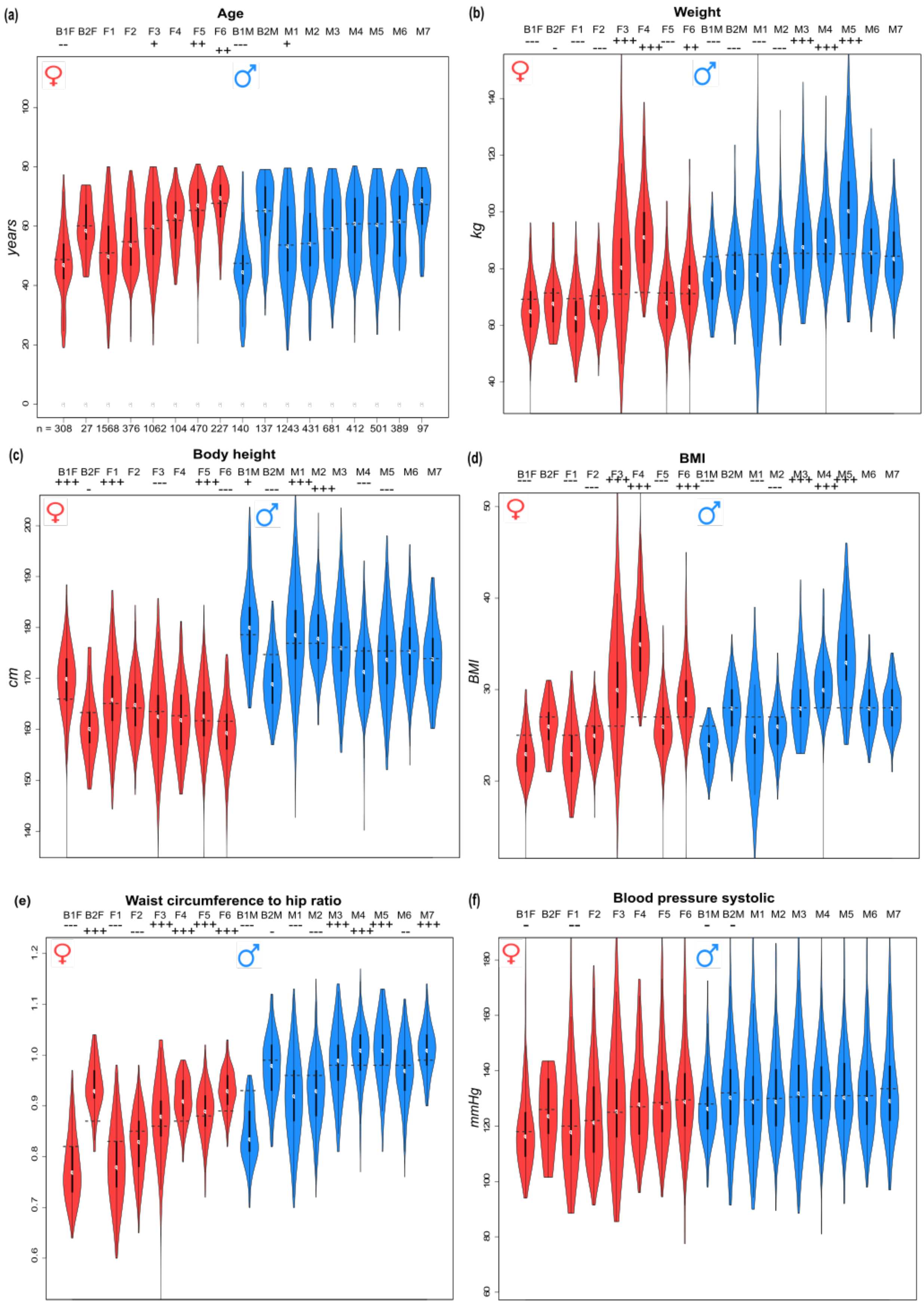
Distribution of age within the body types reflects the target age range of the LIFE study between 40 and 80 years, and reveals that the body type chronology has been chosen according to an increasing median age of the corresponding participants (Figure 4 a). [Appendix B The ageing human body shape] Female body types show a broader range of median ages, whereas male body types M1 and M2, and M3 to M6 have very similar age compositions, respectively. The gender-unspecific body type B2 gathers elder people than B1, and B1 predominantly collects women and B2 men. Variability in male body types is higher than in female ones except for F3, which gathers overweight and obese participants of all ages (see also below). The body types refer to differing and partly specific age ranges. With this, the complete age range of the LIFE study population is covered by the body types.

With regard to body weight we see higher average weight of male body types whereas body types B1 and B2 showed similar values (Figure 4 b). Several body types are outstanding with very high weights, in particular F3 and F4 among female body types, and M5 among males. A high variability within each of the body types can be seen, especially in F3 and M1, which is potentially due to the high number of subjects belonging to these body types on the one hand, but also because of the wide range of their values.

In the previous chapter, we have stated that participants between 50 and 59 years obtain the highest weight levels, followed by a decline in advanced age. This age-related effect can be observed also looking at the body types, but in a more complex manner: F3, F4 and M5 stand out with very high weight and contain participants of a high age range with mean value of about 60 years. In turn, 'youngest' and ‘oldest’ body types (F1 and M1, F6 and M7) showed a considerably lower body weight.

In the next step we have utilized the reference groups to relate the body types’ weight distributions to the one of the overall study population, which explicitly adjusts our analysis for age depending effects. F1, F2 and F5 had lower weight than their reference group (see “+” and “–“ in Figure 4). On the other hand, F3, F4 and F6 showed significantly higher weights. The M-body types are similar: Younger age body types M1 and M2 are lighter than the corresponding reference groups, while M3 and M5 are heavier. The gender-unspecific body types B1 and B2 showed significantly lower body weight values than the reference groups for women as well as for men, which is due to their slim or small body characteristics.

Figure 4 Anthropometric parameters stratified by the body types in terms of violin plots. Dashed lines indicate median values of the reference age groups, "+" and "-"indication in the header indicate significant differences between the body types and their reference groups with p-values of <0.1 (+/-), <0.01 (++/--) and <0.001 (+++/---), respectively.



Inspection of body height reveals not only that the male body types were taller than female ones, but also that body height decreases with increasing mean age of the body types (compare Figure 4 a and c). However, some details cannot be explained by age effects solely: F5 body type was slightly taller than expected, i.e. taller than F4 and F6. M4 and M5 on the other hand were particularly small body types.

BMI is a combination of the parameters weight and body height, which have been discussed before. It is to be noted that participants' body measures have been adjusted for body height prior to definition of the body types. BMI characteristics of the body types consequently follow median weight closely (compare Figure 4 b and d). Importantly, BMI showed much less variability than weight, which indicates that BMI is a major determinant for body typing, whereas other parameters contribute less.

More differences between weight and BMI characteristics can be observed in the B-body types: In general, median weight slightly differed between B1 and B2, whereas median BMI showed considerable difference. B1, which is dominated by female participants, had lower values than B2, collecting mainly male participants. The BMI values of women in B1 and B2 were lower than BMI of men in the same body type. Another aspect is that female body type F3 covers the whole range of BMI values analogously to the parameter weight. Among male body types, M1 (the lean and young age body type) and M5 (overweight body type) contained participants with the broadest range of BMI values.

The strongest differences in comparison to the reference age groups can be found in overweight and obese body types F4 and M5, which were expected to associate with increased health risks and disease prevalence as addressed in the following.

Waist to hip circumference ratio is less specific for the body types in most cases, as reflected by the less pronounced differences between median WTH of the body types and median WTH of the reference groups (Figure 4 e). In line with previous discussion, male body types showed higher WTH values. For the B-body types we can find an enhanced differentiation between B1 and B2 in both genders, which is mainly driven by the larger proportion of women in B1 and men in B2. In this context it is to be considered that the difference between median WTH of body types F3, F4 and M5 and their corresponding references groups was less pronounced than between weight and BMI, which means that these overweight body types are less distinct when utilizing WTH measurement.

With regard to blood pressure we here restrict to systolic blood pressure, diastolic blood pressure showed only very small differences to the reference age groups (data not shown). In general, we see higher systolic blood pressure in male body types than in female body types, whereas 'older' body types F4 to F6 showed highest blood pressure (Figure 4 f). Median blood pressure in male participants was almost constant in all body types. However, a high variability can be observed, leading to the assumption that blood pressure is related to a low extend to body type.

In comparison to the reference groups, 'younger' body types F1, F2, M1 and M2 are characterized by lower blood pressure. The strongest deviation from the reference group can be observed for B-body types showing low values in both genders.

Contrary to expectations, there is only few body type specific deviation from the reference data, and also only relatively small differences between the body types, which are additionally overlapping due to the wide range and variability of blood pressure values.

Table 4 summarizes body type characteristics with regard to anthropometric measures and blood pressure in terms of the difference between body type specific median and median of the corresponding reference age group. Noteworthy is that due to large number of observations, also smaller differences between body types and reference groups can lead to significant p-values.

Taking together, we can see the tendency of being overweighted in F3, F4, M3 and M5. Vice versa there are attributes of slenderness in the body types B1 F and B1 M, F1 and M1.

Table 4 Median tendencies of the body types with regard to classical anthropometric parameters and blood pressure. "+" and "-" indicate significant differences between the body types and their reference groups with p-values of <0.1 (+/-), <0.01 (++/--) and < 0.001 (+++/---).

Body type	Weight	Height	BMI	WTH	RR sys
B1 (female)	---	+++	---	---	-
B2 (female)	-	-		+++	
F1	---	+++	---	---	--
F2	---		---	---	
F3	+++	---	+++	+++	
F4	+++		+++	+++	
F5	---	+++	---	+++	
F6	++	---	+++	+++	
B1 (male)	---	+	---	---	-
B2 (male)	---	---		-	-
M1	---	+++	---	---	
M2	---	+++	---	---	
M3	+++	---	+++	+++	
M4	+++	---	+++	+++	
M5	+++		+++	+++	
M6				--	
M7				+++	

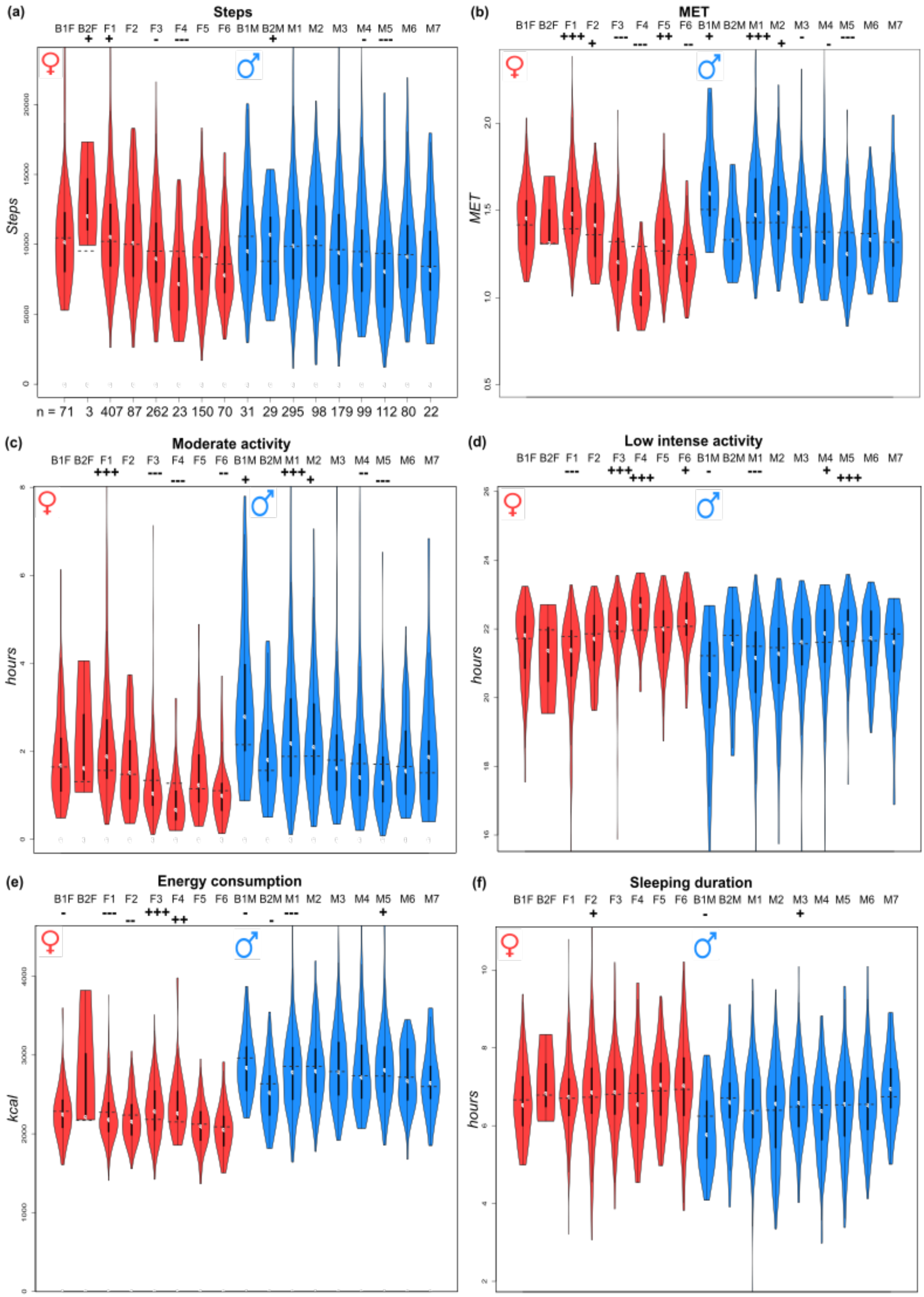
This chapter has shown that the body types collect participants with mainly specific ranges of the selected anthropometric parameters. Several body types deviated from the expected characteristics derived from body type age. These parameters potentially have higher impact on body shape, and therefore also on body typing. In most parameters, gender depending differences were stronger than differences between the body types. We also found lower variation of older body types concerning multiple parameters.
Eventually, body types stratify the study population with increased resolution compared to simple classifications according to, e.g. BMI or WTH, which results in body type specific parameter ranges. Combinations of these characteristics are a major determinant of the body types, and moreover relate to health and disease risk.

5.3 Physical activity parameters of the body types

In this chapter we will present data on physical activity parameters with regard to the body types: With regard to step number there was a high variability within the body types with values up to a maximum of about 20,000 steps (Figure 2 a, Figure 5 a). The median number of step of the different body types varied up to about 1,000 steps. The body type with the highest number of steps, B2 (female participants), only represents three participants with available actometer data, and will therefore not be considered in further discussion. Significantly low number of steps can be observed in the overweight body types F4 and M5. Interestingly, F3, also a high weight and BMI body type, did not show a particularly low step number in comparison to the other body types, but slightly lower step number than the reference group. This putatively reflects that participants with F3 body type are more active compared with F4 body type, but still on a low level with regard to expected activity in the corresponding age range.

Metabolic equivalent (MET) values are less variable and especially more specific for female body types than number of steps (Figure 5 b). [Appendix B The ageing human body shape] The highest values with significant differences to the reference groups can be observed in B1 (female), F1, M1, M2, and in B1 (male) with the highest MET values overall. A markedly low MET can be found in F3, F4 and M5, which have already been discussed to be the risk body types in the context of BMI. It is to be noted that F3 and F4 showed the same strong deviation from their reference groups, which partly differs from the parameter number of steps. In general, MET characteristics of the body types can be considered as inverse to BMI: The median MET and BMI values of the body types are anti-correlated (r = -0.87).

Figure 5 Activity parameters of the body types. See legend of Figure 4.



The time spent in moderate and low intensity activities were nearly inverse as discussed before, however these parameters showed a high variability (Figure 5 c and d,Figure 5

Activity parameters of the body types. See legend of Figure 4.). Of special interest is that male body types exhibited a longer time spent in moderate intensity activities, which can be explained by the higher percentages of men working in physical labor. Significantly short times in moderate and long times in low intensity activities can be observed in F3, F4 and M5 as expected. A higher activity level, as indicated by longer time in moderate intensity activities, is shown by the 'younger' body types F1, M1 and M2, but also by M7, a body type collecting mainly oldest male participants. The latter could indicate that this parameter is characterized by higher intensity when being active. Higher activity levels cannot be observed in general.

Total energy consumption is related to MET, however it is an absolute measure and does not imply constitution of the individual participants. In general, there are no apparent body type specific ranges or patterns visible (Figure 5 e). Male participants showed higher energy consumption values than female as discussed before, which can also be observed in the body types. We see a slight tendency of overweight and obese body types F3, F4 and M5 showing higher energy consumption than the corresponding reference groups, and a slide decrease of energy consumption in older body types for both genders.

Sleep is an important factor and represents major characteristics of physical activity and lifestyle. [12, 30] However, duration of sleeping reveals high variability in combination with only minor differences between the body types (Figure 5 f). Considerable deviations from the reference groups can be found for F4 and B1 (male), which showed short sleeping durations. These findings are partly opposed to other risk factors: While participants in overweight body type F4 slept shorter in average, participants in the other female overweight body type F3 have slightly longer sleeping duration than the reference values. Male participants in B1, who are characterized by lower BMI and higher activity level, show the shortest sleeping duration of the entire study population.

Table 5 summarizes deviations of the body types' activity parameters from the corresponding reference groups. Most activity characteristics are in line with BMI and weight risk factors, in particular the rather inactive body types F3, F4, M4 and M5. Vice versa, we observe high physical activity in the younger and lean body types F1 and M1. On the other hand, sleeping duration is another known risk factor for psychiatric diseases, but partly also for cardiovascular and metabolic diseases. However, it appears mostly independent of weight related risk, and therefore also independent of body type.

As actometer data is available for only about 2,500 participants, these findings need further validation in future population studies involving both anthropometric and activity assessment.

Table 5 Median tendencies of the body types with regard to activity parameters and blood pressure. "+" and "-"indicate significant differences between the body types and their reference groups with p-values of <0.1 (+/-), <0.01 (++/--) and <0.001 (+++/---), respectively.

Body type	Step number	MET	Moderate Intense Activity	Low Intense Activity	Total Energy Consumption	Sleeping Duration
B1 (female)					-	
B2 (female)	+				-	
F1	+	+++	+++	---	---	
F2		+			--	+
F3	-	---	---	+++	+++	
F4	---	---	---	+++	++	
F5		++				
F6		--	--	+		
B1 (male)		+	+	-	-	-
B2 (male)	+				-	
M1		+++	+++	---	---	
M2		+	+			
M3		-				+
M4	-	-	--	+		
M5	---	---	---	+++	+	
M6						
M7						

5.4 Age related development of the body types

Age is one major driver for changes in the parameters discussed in the last subchapters. This body type related view will now be supplemented with the evaluation of selected parameters as a function of age separately for each body type. [Appendix B The ageing human body shape] For this, we generated smoothed curves of BMI, MET, and sleep duration as a function of age (Figure 6). The mixed gender body types B1 and B2 were discarded from this analysis due to insufficient sample size. For each of the body type discussed, we will give information on deviation from the reference groups in parenthesis (see previous subchapter, Table 4 and Table 5).

Figure 6 Parameters BMI, MET and sleep duration as function of age at time of measurement. Curves were smoothed for each body type. Thick black lines indicate the mean parameter development averaged over all female (left panels) and male participants (right panels), respectively.

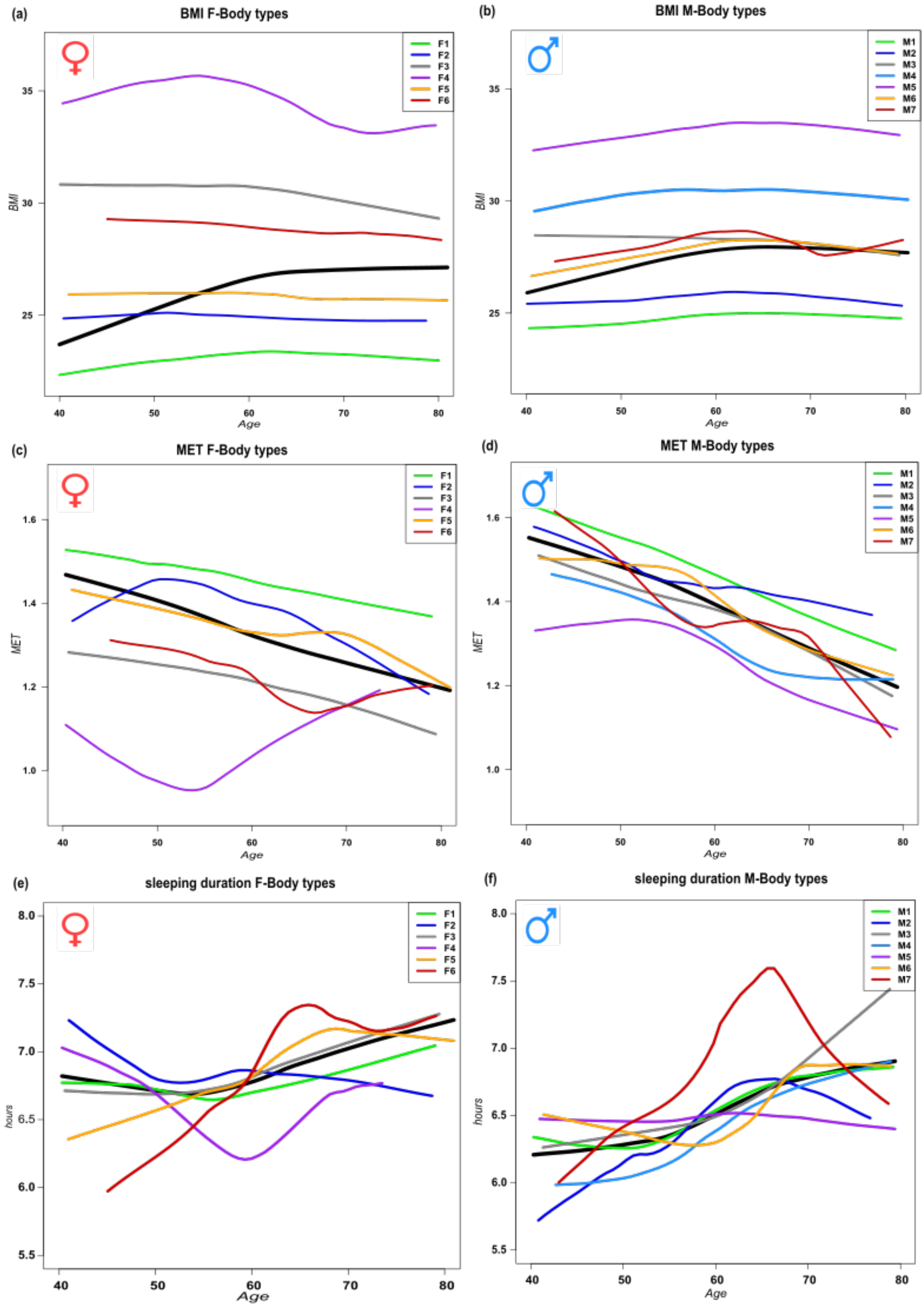


Figure 6 a and b show BMI curves of female and male body types, respectively. The reference lines of overall mean BMI shows lowest values for youngest participants, followed by a steady increase to a plateau of nearly constant BMI from an age of about 60, as already discussed before. Female body types show almost constant BMI levels at all ages, indicating again that BMI is a major determinant of body type, whereas age is only a secondary factor (Figure 6 a). Only F4 (+++) reveals some variability, however on highest BMI level overall. Male body types reveal similar courses, with very steady curves on different BMI levels (Figure 6 b). M3 (+++), M6 and M7 approximate the overall mean BMI development and are the only body types which intersect in their BMI range. In general, we find the BMI lines running on steady levels. This means that the BMI values of the participants collected in a particular body type do not considerably differ with regard to age.

Similarly, curves of MET show mainly parallel courses with negative slope and a general bias towards lower values in female body types as expected (Figure 6 c and d). The F1 (+++) age line runs above the mean age line and confirms the tendency of this age group. The line is decreasing with a lower slope than the mean age line. F3 (---) and F6 (--) can also approve their tendencies but showing lines running below the mean age line, whereas the F3 (---) line is indicated by a similar slope than the mean age line. The lines of F2 (+) and F4 (---) show more diverse patterns with local maximum/minimum at about 55 years of age, followed by decreasing/increasing values, respectively. For male body types, we find M1 (+++) showing high values and a slope very similar to the reference line. M5 (---) embodies the other extreme with lowest values. In general, there is monotonous decrease of MET values upon aging in almost all body types. Variability is thereby higher in female body types than in male ones. In comparison to BMI curves, we observe less body type specificity in terms of data ranges due to the fact that MET values have not explicitly been included in the body typing process.

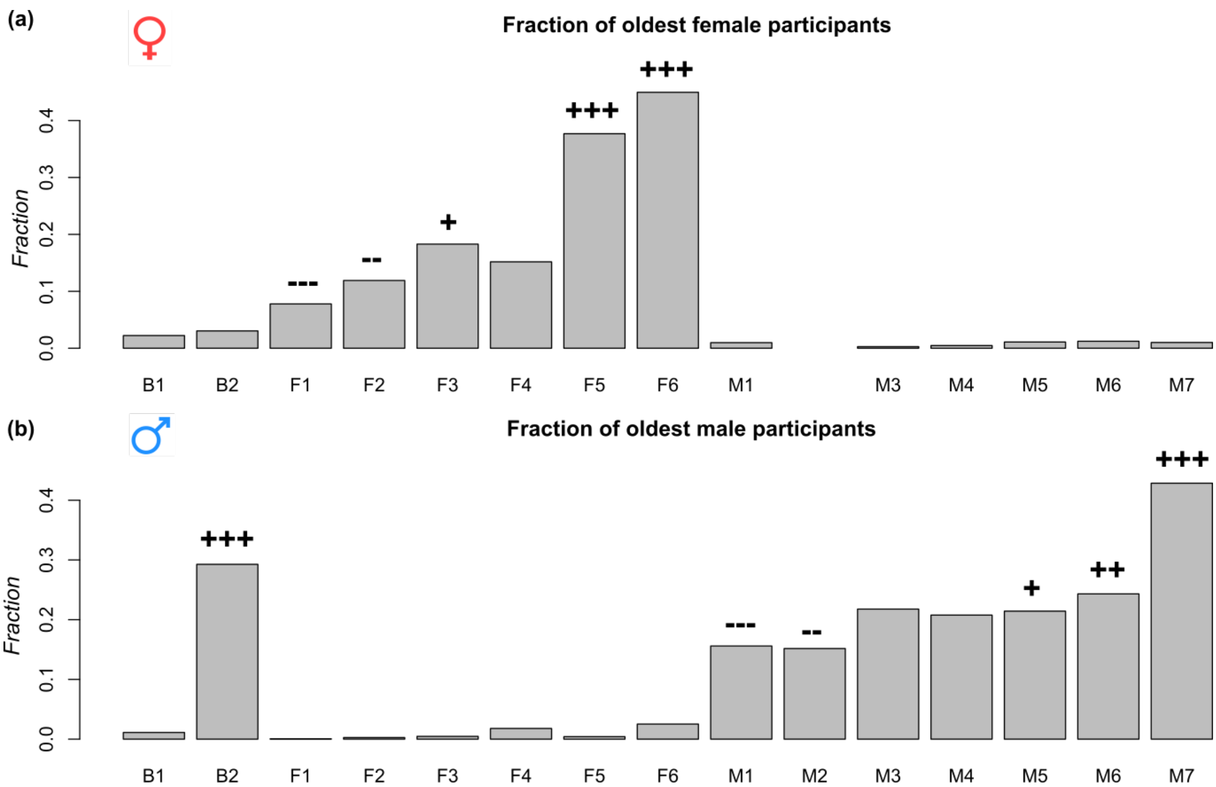
Regarding sleeping duration, we found highest values in female body types. Shortest sleeping duration of women can be found in the early 50's with increasing duration in further years. Male body types have a steep slope between an age of 60 and 70 years potentially due to retirement from work as observed in the previous section. We could only identify few body types with a significant deviation from their referring age group, but there are various body types with notable age courses: The old body types F6 and M7 show peaks of sleeping hours around the age of 65 (retirement from work), reflecting that the necessity of getting up early can be a reason for fewer sleeping hours. The body types F2 (+), M2 and M5 exhibit fewer sleeping hours in older years of age, which is different from the general tendencies. The graph of body type M5 runs steadily on a level around 6.5 hours, which is an extremely low level especially for older participants. This may be caused by the high BMI in this body type, as sleep interfering diseases like sleep apnea are more common among obese people. We can confirm that sleeping duration changes upon ageing, and that body type specifics play only a minor role.

In summary, BMI values are body type specific and almost invariant upon aging. Contrary, MET values and sleeping duration are age-dependent without pronounced body type specificity. MET shows a consistent trend towards lower values upon ageing. Sleeping duration strongly varies within the body types and shows no consistent trends.

5.5 Body types of the oldest participants

We noticed a characteristic distribution of oldest participants of the LIFE study in the body type specific violin plots of the parameter age and in the development curves of the aging process. We therefore, the question wondered in which of the body types these participants accumulate. The proportion of participants older than 70 years in each of the body types is visualized in terms of bar plots separately for both genders (Figure 7). [Appendix B The ageing human body shape] The significance of enrichment has been calculated using Fisher's exact test.

Figure 7 Distribution of oldest participants in the body types. "+" and "-"indicate significant enrichment with p-values of <0.1 (+/-), <0.01 (++/--) and <0.001 (+++/---), respectively.



In the B body types, older participants make up only a small fraction, except of the significant increase of older men in B2 with about 30%. Older women make up between 10% and 20% only in the body types F1 to F4, but significant increase with about 40% could be observed in F5 and F6. M–body types show a similar characteristic with low percentages of oldest participants in M1 to M6 (about 20% of individuals >70 years), and a significant enrichment in M7 (about 40%). These findings are in line with the discussion above, and determine F5, F6 and M7 as characteristic body types of the old people (>70 years). B2 comprises only a low number of participants; however high percentage of old men seems to be an essential characteristic of this body type. We suppose that these old participants do not fit to any other body type due to their differences to a typical male body shape that could be observed.

5.6 Distribution widths

In the previous chapters we mainly focused on median values of ensembles of participants, and on their variability as represented in the violin plots. This is a valid primary evaluation, as the parameters in the study mostly follow normal distributions. In the following we will add a more detailed investigation of the parameter distributions of the body types.
Figure 8 exemplarily shows the distribution of the BMI values in four selected body types. Two of the body types show a narrow distribution (F2 and M7 in Figure 8 a and d), while the other two are characterized by a broad distribution (F3 and M5 in Figure 8 b and c). Broad and narrow distribution reflects 'collective' and 'specific' body types with regard to the BMI, respectively.

For detailed investigation of the specific and collective parameter distribution in the body types, we calculated the standard deviation of each parameter in each body type. According to this a body type will be defined as 'collective' or 'specific' if a parameter's standard deviation was particularly high or low. For this we applied the inter-quartile criterion to find outlying high and low values in the set of standard deviations of all body types within a parameter. This criterion implicitly adjusts for data ranges and for asymmetric distributions. Table 6 and Table 7 provide an overview about specific and collective distributions of the classic anthropometric and the activity parameters.

Figure 8 Box plots of body type density distribution of the BMI

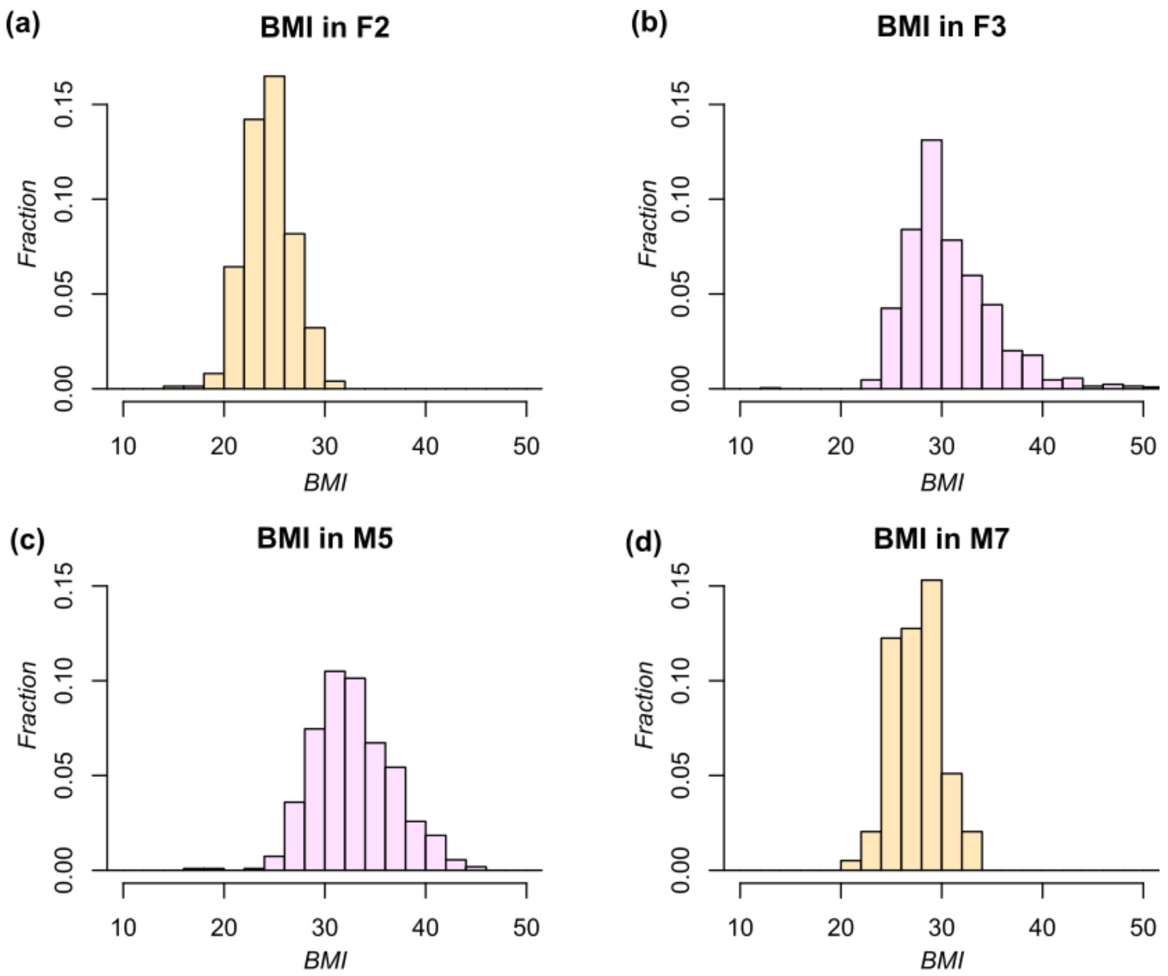


Table 6 Overview of collective and specific distributions of anthropometric parameters in the body types

Body type	**Age**	**BMI**	**Weight**	**Height**	**WTH**	**WhtR**
B1(female)			specific	collective		
B2(female)	specific		specific		specific	specific
F1			specific			
F2			specific	specific		specific
F3		collective	collective			collective
F4	specific	collective	collective		specific	collective
F5	specific					
F6	specific				specific	collective
B1(male)		specific		collective		specific
B2(male)				specific		collective
M1	collective			collective		
M2						
M3						
M4						
M5		collective	collective	collective		collective
M6						
M7					specific	specific

Table 7 Overview of collective and specific distributions of activity parameters in the body types

Body type	**Steps**	**MET**	**Moderate intensity**	**Low intensity**	**Energy uptake**	**Sleep**
B1(female)	specific				specific	specific
B2(female)	collective	collective	collective	collective	collective	collective
F1						specific
F2						
F3						
F4	specific	specific	specific			
F5						
F6	specific	specific	specific			collective
B1(male)		collective	collective	collective		
B2(male)				collective		specific
M1		collective	collective	collective		
M2						collective
M3						
M4						
M5						collective
M6						
M7		collective				

In the tables, collective and/or specific body types for most anthropometrical and activity parameters except for energy uptake can be found. For the latter similar, distributions across the body types could be observed. In general, F1 and F2 show consistently narrow distributions and are specific for several anthropometric parameters. Contrary, M1 and M5 are consistently collective with broad data distributions. Other body types, such as F4 and F6, are specific for some parameters and collective for others.

F3, one of the health risk body types, is the only female body type with the tendency of being collective. Old body types are rather specific (F5, M6, and, partially, F6 and M7). The gender-unspecific B-body types are specific or collective for selected parameters without a clear tendency. An interesting example for this is B2 (female), which is specific for most anthropometric parameters, however collective for all activity parameters. This could be due to a low number of participants in this body type.

Few body types (M3, M4, and M6) are not assigned as specific or collective for any of the parameters. Inspection of their parameter distributions reveals that these body types show tendency to be collective with broader distributions (data not shown).

In summary, this approach provides a more detailed view on specificity of the body types with regard to the anthropometric and activity parameters, and it supports data visualization in terms of violin plots. The information will help to understand important aspects of the study population and to holistically characterize the body types.

6 Body types and their prevalence of selected diseases

In the previous chapters, we examined the body types and their relation to anthropometric and activity parameters. These findings and their discussion in the context of common knowledge provide a profound and detailed base of information. As already mentioned, some traits of the different body types may be risk factors, e.g. the high BMI values and low MET values in F3, F4 and M5. Consequently, we now add information on prevalence of selected diseases to evaluate associations of these to the body types. Table 8 lists selected diseases and their respective prevalence in the LIFE study population stratified by gender and age. These diseases cover a range from cardiovascular over mental to autoimmune disorders. Even in very rare occurrence prevalence rates vary a lot through the different age groups, e.g. myocardial infarction or hypertension with up to 75% in the older subgroups.

Table 8 Prevalence of selected diseases in the LIFE study population stratified by age and gender

Disease	Gender	Age 40-49	50-59	60-69	70-79
Hypertension	♀	205 [1] (17%) [2]	523 (42%)	827 (62%)	704 (74%)
	♂	382 (32%)	552 (53%)	849 (70%)	779 (75%)
Hyperlipidaemia	♀	219 (15%)	331 (27%)	492 (37%)	441 (46%)
	♂	271 (22%)	366 (35%)	533 (44%)	432 (42%)
Myocardial infarction	♀	2 (0%)	11 (1%)	22 (2%)	24 (3%)
	♂	6 (0%)	26 (2%)	62 (5%)	98 (9%)
Angina pectoris	♀	5 (0%)	14 (1%)	38 (3%)	59 (6%)
	♂	6 (0%)	33 (3%)	70 (6%)	103 (10%)
Arthrosis	♀	188 (13%)	300 (24%)	502 (38%)	464 (49%)
	♂	115 (10%)	201 (19%)	295 (24%)	309 (30%)
Diabetes	♀	25 (2%)	76 (6%)	173 (13%)	182 (19%)
	♂	41 (3%)	101 (10%)	244 (20%)	234 (23%)
Depression	♀	235 (16%)	214 (17%)	189 (14%)	104 (11%)
	♂	61 (5%)	83 (8%)	93 (8%)	53 (5%)
Rheumatism	♀	52 (4%)	63 (5%)	87 (7%)	87 (9%)
	♂	30 (2%)	33 (3%)	59 (5%)	67 (6%)

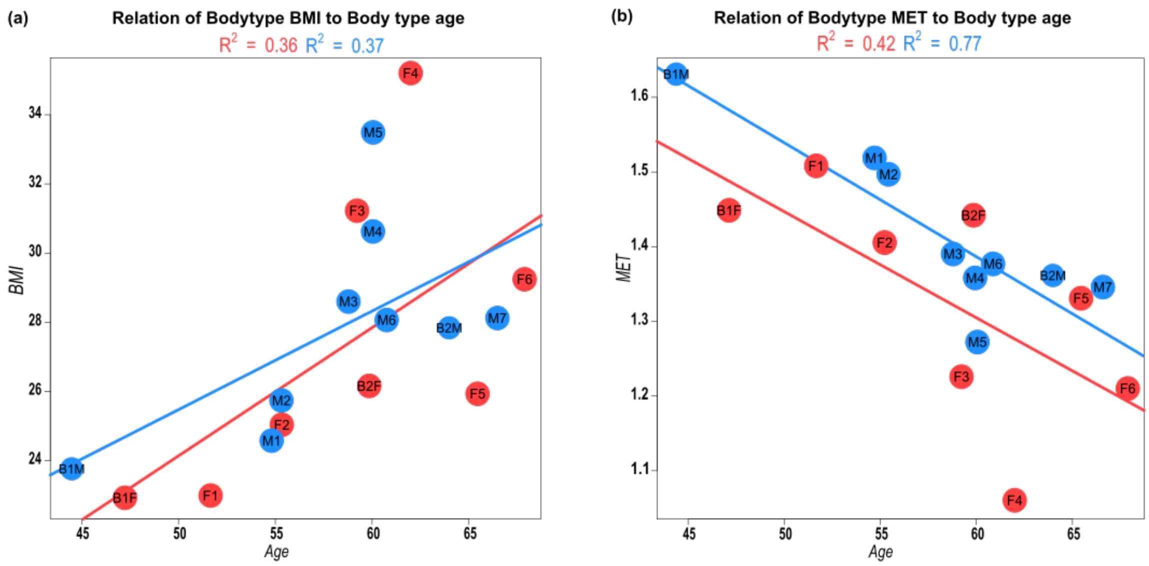
[1] Total number of participants with previous diagnosis

[2] Percentage in the corresponding subgroup

6.1 BMI and MET as risk factors

In the following chapters, the relation of disease prevalence to the risk factors age, BMI and MET will be evaluated. As discussed earlier, body type BMI and MET are strongly anti-correlated. In a next step, we have investigated in detail how these two factors develop upon ageing. For this, we generated scatter plots showing the mean BMI and MET of the body types as function of the mean age of participants per body type (Figure 9)

Figure 9 Linear regression analysis of mean body type BMI (panel a) and MET (b) as a function of mean body type age. Regression was performed for both genders separately, corresponding R² are given in the heading.



Body type BMI increases with increasing age as already shown for the overall study population (Figure 9 a, see also Figure 1). Slopes of the linear regression lines as well as R^2 are similar for both genders; however they reveal only a small correlation. Body types with a considerably high BMI (F3, F4, M4, and M5) are consequently above the regression line, the other body types are located around the line. In this way, we can confirm the relation between age and BMI of the body types, with strong outliers of the high BMI body types.

In agreement with the overall population characteristics, mean MET per body type is decreasing with age, resulting in negative slope of the regression lines (Figure 9 b). These lines are running in parallel, and for male body types fewer scatter and higher R^2 can be observed compared to female body types. In turn, we observe the strongly outlying female body type F4 and, to a less degree, the male body type M5. Both body types show low mean MET and are located below the regression line, which means that individuals with these body types are less active.

In general, these results are in line with our previous findings. Moreover, this approach adjusts evaluation of BMI and MET, and of disease prevalence as shown below, for age. Summarizing the main finding which is the linearity of BMI and MET with exceptions of obese and inactive body types. The assumed health risks will be examined regarding disease prevalence in the following chapters.

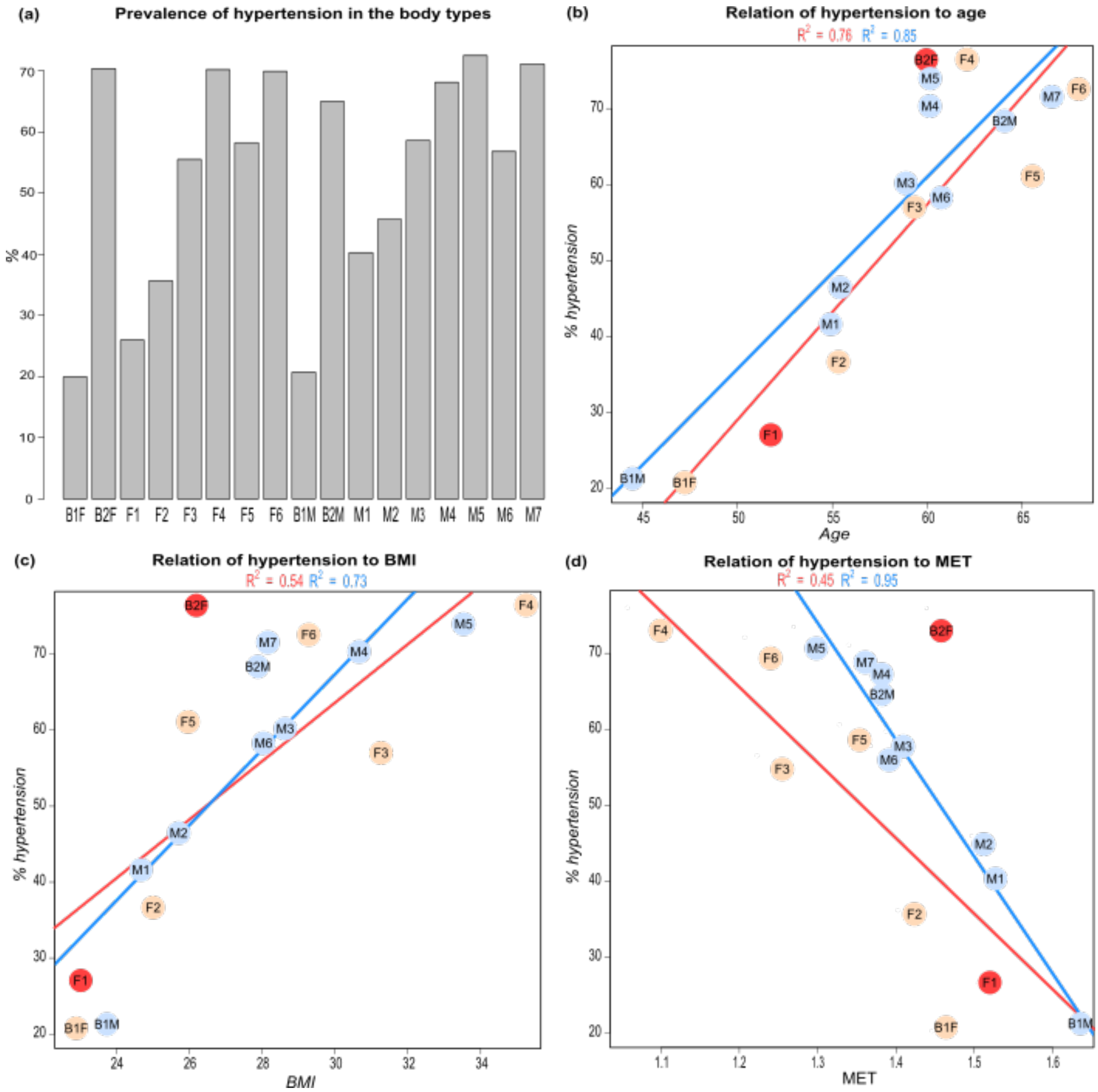
6.2 Hypertension

We investigated the relation of age, BMI, and MET with the prevalence of selected diseases: The LIFE study collected data on hypertension, angina pectoris and heart attack as diseases of the cardiovascular system, diabetes and hyperlipidaemia representing metabolic diseases, rheumatism as an autoimmune diseases, arthrosis as a disease of the musculoskeletal system, and depression as a non-organic type of disease. [56] We separately have examined the relation of age, BMI and MET to the particular disease prevalence, and afterwards judged the influence of age, constitution and body type on the disease. Our approach included two complementary regression analyses: Firstly, we applied linear regression models to evaluate disease prevalence as function of age, BMI and MET on body type level. Secondly, we used logistic regression on individual level based on age, BMI, MET, and disease history of each participant.

For the first approach, we generated scatter plots where the x-axis represents the mean values of age, BMI or MET parameters in each of the body types, respectively, and the y-axis presents the prevalence of the disease in the body types (i.e. percentage of individuals with this body type suffering from the disease). The prevalence was simplified in terms of the fraction of individuals in a body type who indicated that they at least once suffered from a certain disease. That means that we will assess the prevalence in a body type-centered view and in relation to the other mean body type parameters. Additionally, we provide coefficient of regression (R^2), as an indicator of the linearity of the relation between the prevalence and the predicting parameters.

For the second approach, we applied logistic regression analysis for male and female participants separately, using previous occurrence of the disease as dependent variable and the body types as predictors. Additionally, BMI and age of the participants have been included as co-factors. The model provides coefficients and p-values for the body types and the co-factors, allowing us to judge which body types significantly associate with disease prevalence. In the following, we will describe the gender-specific linear regression lines for each disease and their relations to the body types. Furthermore, we will indicate body types with high coefficients and significant p-values in the logistic regression analysis.

Figure 10 Prevalence of body types for hypertension at the day of examination as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). Linear regression analysis was performed for both genders separately, corresponding R² are given above each plot. Body types in dark coloring showed significant association to disease prevalence according to logistic regression (p-value < 0.05).



For investigation of hypertension prevalence, we have selected participants with blood pressure values of 140mmHg and higher. [4, 41, 104] As shown in the previous results about 1,300 participants were under medication (ATC group C), which introduces a bias towards hypertension prevalence. High prevalence can be found looking at the body types B2 (female and male), F4, F6, M4, M5, and M7 (Figure 10 a): More than 66% of the individuals with these body types are or were suffering from hypertension. In turn, only body types B1 (female and male), and F1 collect less than 33% of individuals with previous hypertension diagnosis meaning that these body types are less vulnerable to suffer hypertension. The lower prevalence is especially noteworthy regarding relation to the regression line of BMI and MET.

The regression lines for the relation of hypertension prevalence and age of the body types show a steep slope accompanied by high R^2 values, revealing a strong relation with increased disease prevalence in older ages as expected (Figure 10 b). The male line runs slightly above the female one. Few body types are located distant from the regression line: B2F, F4, M4, and M5 show higher and F5 less share of hypertension, respectively.

Linear regression of hypertension and BMI also reveal positive slopes and relatively high R^2 for both genders (Figure 10 c). The lines are crossing at a BMI of 27, for lower BMI values female body types exhibit higher, and after that value lower prevalence. Body types distant from regression lines are B2F, F5, F6, and M7 with higher prevalence, and B1F, B1M, F1, and F3 with lower disease prevalence.

For MET we found a negative relation, indicating that higher physical activity associates to lower hypertension prevalence in the body types as expected (Figure 10 d). Slope of the lines and also R^2 differs between the genders: Male body types almost perfectly arrange along the linear regression line ($R^2 = 0.95$). In other words, 95% of variability of hypertension prevalence in male body types can be explained by the factor MET. For female body types the association is less strong, but still reliable ($R^2 = 0.45$). Also slope of the regression line is flatter for the female body types (-99.3, compared to -154.9 in male body types). The body types B1F and B2F show larger distance from the regression line, whereas no outlying male body types can be observed.

As a next step, logistic regression analysis has been performed on individual participant level. It turned out that F1 and B2F are significantly associated with hypertension occurrence (p-values < 0.05). Coefficient of F1 is negative, meaning that belonging to body type F1 results in less prevalence of hypertension (adjusted for age and BMI). B2F has positive coefficient value, but again with the limitation of a low number of participants in this body type. Co-factors BMI and age also significantly contribute to the regression model as expected (p-values < 0.001).

In summary, prevalence of hypertension has been found to be linearly associated to age, BMI and MET, with the body types B2F and F1 as significant predictors. Thus, the prevalence in these body types is supposed to be related to other influencing factors. In the case of B2F we explored that the body type itself is characterized by several risk factors, i.e. higher age and weight as well as low activity level. On the other hand, we did not observe prevalence for hypertension explaining less than 20% of variability in any body type, which can be attributed to the age range of the study population. The body types F4 and M5 exhibited high percentages of the disease, which is in turn, significantly related to BMI, MET and age in our

model. This is supporting the hypothesis that these body types are associated with high risk for further diseases especially cardiovascular diseases like angina pectoris, myocardial infarction or stroke.
Comparing these findings with the fact that hypertension is a common disease with high prevalence especially in older parts of the population, we can state that our findings are in line with expectancy but also with the assumption that some body types imply increased risk beyond their BMI characteristics. [4, 104, 105]

In the following chapters, we will discuss the results of linear and logistic regression analyses with regard to the different diseases. Table 9 aggregates the relevant data in terms of the linear models using age, BMI and MET as predictors, and of a list of body types which have been identified as significant factors in logistic regression models.

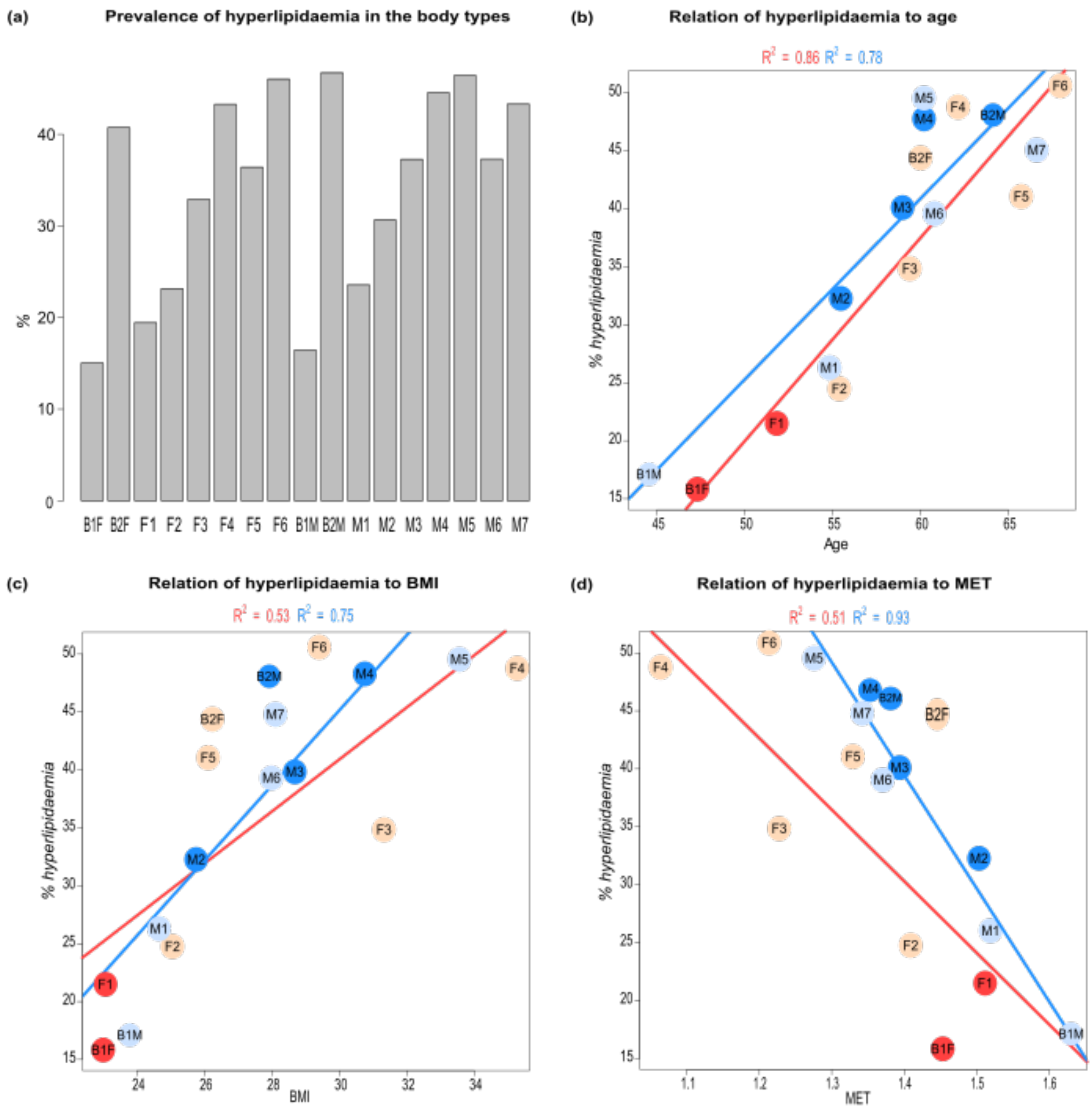
Table 9 Overview about regression analyses of disease prevalence, the slopes (i.e. coefficients in linear regression) represents strength of association of age, BMI, and MET to the disease, respectively. Values are only given if R² in the corresponding model exceeds 0.5. Body types found as significant factors in logistic regression are listed with '+' and '-' signs in parenthesis indicating positive and negative coefficients for the body types, respectively.

Disease	Gender	Slope age	Slope BMI	Slope MET	Significant body types
Hypertension	♀	2.8±0.6	3.9±1.5		B2F (+); F1 (-)
	♂	2.5±0.4	5.0±1.1	-153.9±12.7	
Hyperlipidaemia	♀	1.7±0.3	2.2±0.9	-61.1±24.8	B1F & F1 (-)
	♂	1.6±0.3	3.3±0.7	-97.7±10.1	B2M, M2, M3 & M4 (+)
Myocardial infarction	♀				F1 (-)
	♂	0.4±0.1		-19.6±7.2	
Angina pectoris	♀	0.2±0.1			F1 & F3 (-)
	♂	0.3±0.1	0.6±0.1	-16.6±1.8	
Arthrosis	♀	1.8±0.3	2.5±0.8	-70.2±22.1	F1 & F2 (-), F4 (+)
	♂		1.4±0.3	-40.3±8.1	M3 (+)
Diabetes	♀				B1F, F1, F2, F3& F5 (-); B2F & F4 (+)
	♂	1.1±0.3	2.3±0.6	-69.7±12.1	M1, M2 & M3 (-)
Depression	♀				B1F (-)
	♂				M6 (-)
Rheumatism	♀	0.2±0.1			
	♂	0.1±0.04			M2 (+)

6.4 Hyperlipidaemia

Hyperlipidaemia is another common disease bearing risks for comorbidities especially with regard to the cardiovascular system. [41, 54] Considering the body types B2 (male and female), F4, F6, M4, M5, and M7, more than 45% of the individuals stated that they have been diagnosed with increased level of lipids in the blood at least once (Figure 11 a). A lower percentage of people (< 25%) suffering from hyperlipidaemia can be found in B1, F1, F2 und M1.

Figure 11 Body type prevalence of a previous hyperlipidaemia diagnosis as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10.



Linear regression with the parameter age is indicated by high R^2 values accompanied by a positive slope of the line, revealing a reliable linear relation between age and the prevalence of hyperlipidaemia (Figure 11 b). The BMI regression lines are similar, whereby the male line is slightly steeper with a slope of 3.25 compared to the female line (slope = 2.21, Figure 11c). The R^2 values confirm a linear relation with lower value for female body types. The MET regression line shows a negative slope and is similar to the disease hypertension (Figure 11 d). The male R^2 value of 0.95 reveals almost perfect alignment of the body types along the regression line, whereas the female R^2 value is again lower.
Several body types are significantly predictive indicators in the logistic regression model: B1F, F1, B2M, M2, M3, and M4 (p-values < 0.05). It is noteworthy that among those body types the female body types obtain negative coefficients; the male body types consistently show positive coefficients. This means that the significantly predicting female body types are associated to lower hyperlipidaemia prevalence, while the male ones relate to higher prevalence. The co-factors age and BMI also significantly contribute to the model ($p < 0.05$). In addition to these findings, other risk factors, in particular genetic predisposition of hyperlipidaemia are known. [54] The health risk body types (F4 and M5) showed high prevalence (> 45%), however they are no significant predictors. This can be attributed to the fact, that hyperlipidaemia is frequent in most of the male body types. Furthermore, age and BMI are strongly contributing factors in the logistic regression model.

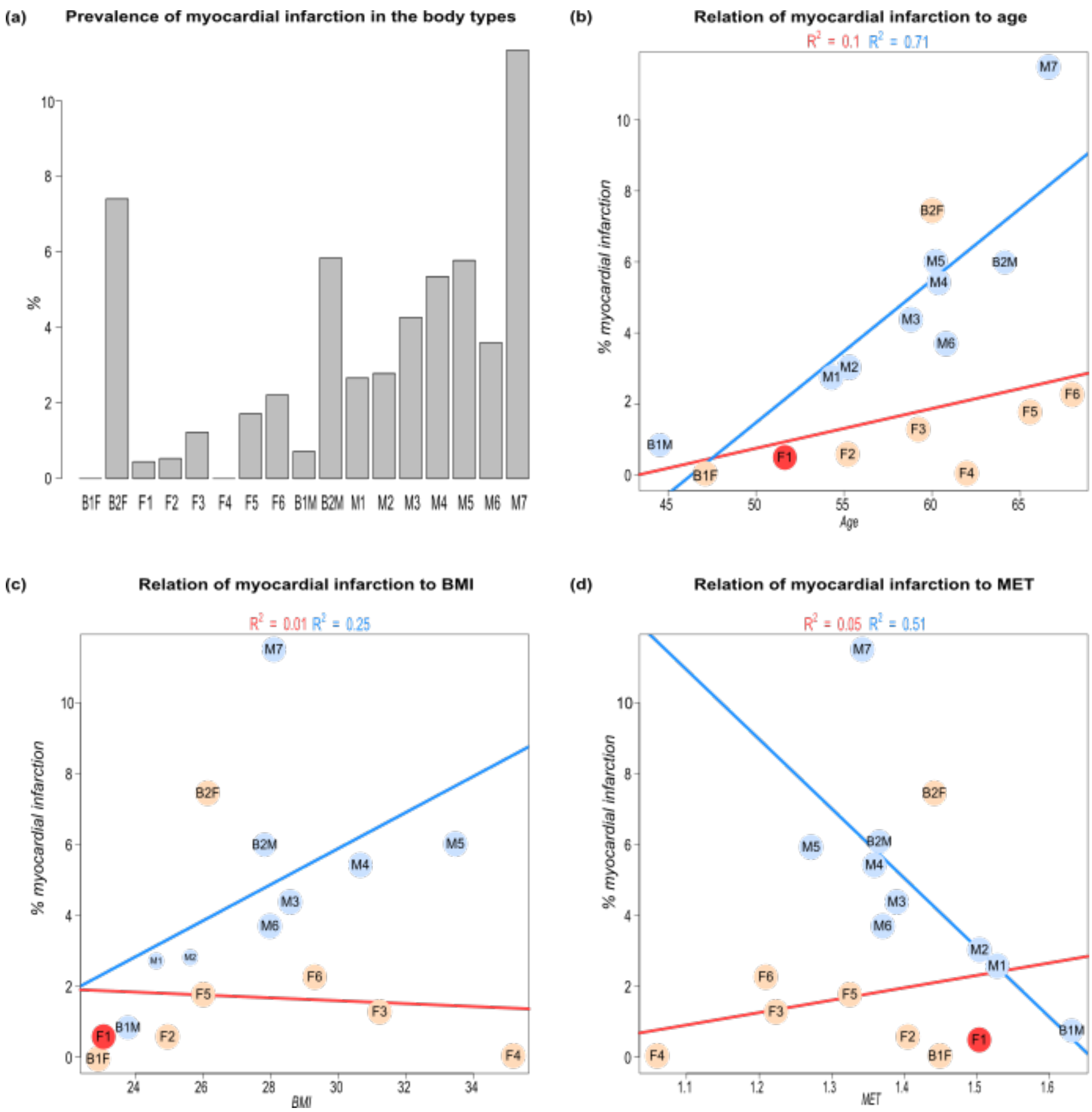
6.5 Myocardial infarction

Myocardial infarction, commonly referred as heart attack, is a severe and life threatening cardiovascular disease, and the major cause of death in the western world. [26, 73, 76, 79, 87,Appendix B The ageing human body shape] The body type M7 shows the highest prevalence towards myocardial infarction, with more than 10% of individuals with this body type having stated to already have suffered a heart attack (Figure 12 a). In general, male body types exhibit higher prevalence of myocardial infarction than female body types, which show values between 0% and 2%. In this context it is to be noted that myocardial infarction is such a severe event, that previous occurrence potentially reduces willingness and/or ability to participate in a study. The prevalence of myocardial infarction is 4.3% in male and 1.2% in female LIFE participants, which is factually lower than the lifetime prevalence in German population (40-79 years) with accounts for 7% and 2.5%, respectively. [34] For this reason, information on previous heart attack is potentially not representative.
The male and the female regression lines of the parameter age differ considerably (Figure 12 b): We can see a positive linear relation for male body types ($R^2 = 0.71$), whereas regression line of female body types shows only weak slope and low coefficient of regression ($R^2 = 0.1$).

B2F represents a protruding outliner with prevalence of about 8%, and thus biases the linear fit of female body types. Removal of this body type from the model results in a much better linear fit (R^2 = 0.59) but with less steep slope compared to the male body types (0.1 vs. 0.4, respectively).

The BMI regression lines are similar: Male body types show a positive linear relation, nevertheless with more scatter and low regression (R^2=0.25), the regression line of female body types has virtually no slope indicating that there is no linear relation of heart attack prevalence to this predictor (R^2 = 0, Figure 12 c). It is to be noted that body types with highest prevalence (B2F and M7) are again outliers in the model, as well in the MET model discussed below.

Figure 12 Body type prevalence of a previous myocardial infarction as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10.



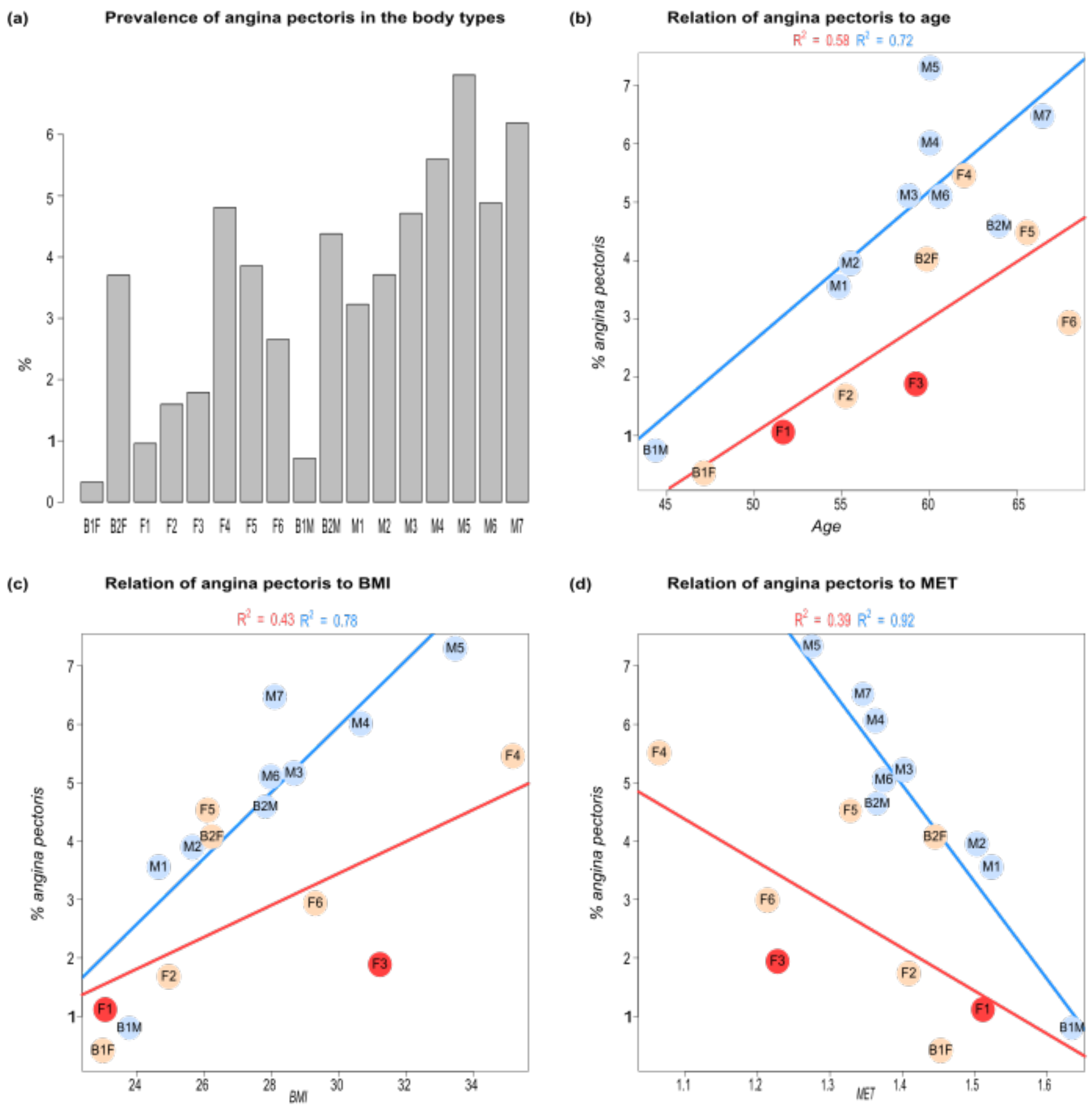
As expected, the regression models using MET as predictive indicators provide no linear relation for the male body types (R^2=0.05) and linear relation with negative slope for female body types (R^2=0.51, Figure 12 d).
Application of logistic regression analysis resulted in only one significant body type: F1 (p-value < 0.05). Interestingly, BMI is not a significant co-factor; age on the other hand is significant (p-value < 0.001). This means that only belonging to the F1 body type and being significantly older contribute to the possibility to predict the dependent variable 'previous heart attack'. F1 thereby has negative coefficient, reflecting that it is less likely for individuals with this body types to have suffered a heart attack before.
In summary, B2F and M7 presented highest prevalence of myocardial infarction. In contrary, F1 is significantly associated with lower prevalence. Interestingly, BMI could be identified to only be a secondary factor, especially for women. However, these findings are limited as heart attack represents a bias due to a high likeliness to mortality on the one hand, and the inability to take part in the study on the other hand. A more detailed discussion of myocardial infarction can be found in Appendix B The ageing human body shape.

6.6 Angina pectoris

Angina pectoris is a cardiovascular symptom, sometimes considered as preliminary state of myocardial infarction. [26, 34] It is indicated by a severe pain behind the breast bone caused by insufficient blood flow to the heart muscles as a result of vascular occlusion. [26, 87] In the following, we will characterize the disease prevalence in accordance to the previous diseases and compare the findings with those derived for myocardial infarction.
The prevalence of the body types for angina pectoris reveals higher percentages for men than for women (Figure 13 a), similar to the distribution of heart attack cases. The highest prevalence can be found in M5 (about 7%), followed by the other male body types M3-M7 (> 5%). Older female body types F4 - F6 also show increased prevalence, however the percentages are decreasing with further age. Contrary, young F-body types F1-F3 and the B1 body type exhibit low prevalence of angina pectoris.
We see a linear relation between age and angina pectoris predisposition (R^2=0.58/0.72) and a positive slope of the regression lines for both genders, which is contrary to the findings for heart attack for female body types (Figure 13 b). Male body types still exhibit a better fit and a higher level of prevalence by about 2-3%. Similar results can be derived from BMI regression analysis, which moreover shows a much steeper slope for male body types (0.57 vs. 0.27, Figure 13 c).

For MET, we see regression lines with negative slope, and that the male body type line is steeper (-16.6 vs. -7.3), which is consistent with the other parameters (Figure 13 d). It is to be noted that corresponding $R^2 = 0.92$ indicates a high correlation.

Figure 13 Body type prevalence of a previous angina pectoris diagnosis as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10.



Significant body types as predictors in the logistic regression model are F1 and F3 (p-values < 0.05). As previously described, F1 and F3 collect mainly younger women and consistently show 'healthy' anthropometrical and activity parameters, which is further supported here. In the logistic models of both genders, age is a significant co-factor (p-values < 0.001), whereas BMI is not significantly contributing to the model (p-value > 0.05).

F4 and M5 exhibit highest prevalence among the female and male body types, respectively. In turn, these body types do not emerge as significant predictors for previous angina pectoris occurrence, which may be explained by the high confounding influence of age.

6.7 Arthrosis

Arthrosis is a disease of the locomotor system. Most forms are degenerative and come along with pain in the joints and lack of mobility. [48, 51] Whereas the cardiovascular diseases discussed in the previous subchapters could be identified more often among men, whereas arthrosis is more likely to occur among women/female body types. [77] In particular, B2F, F3, F5, and F6 showed values of >30% with a maximum of almost 50% in F4 (Figure 14 a). The body type B1 exhibit the lowest absolute prevalence in both genders (15% and 10%, respectively).

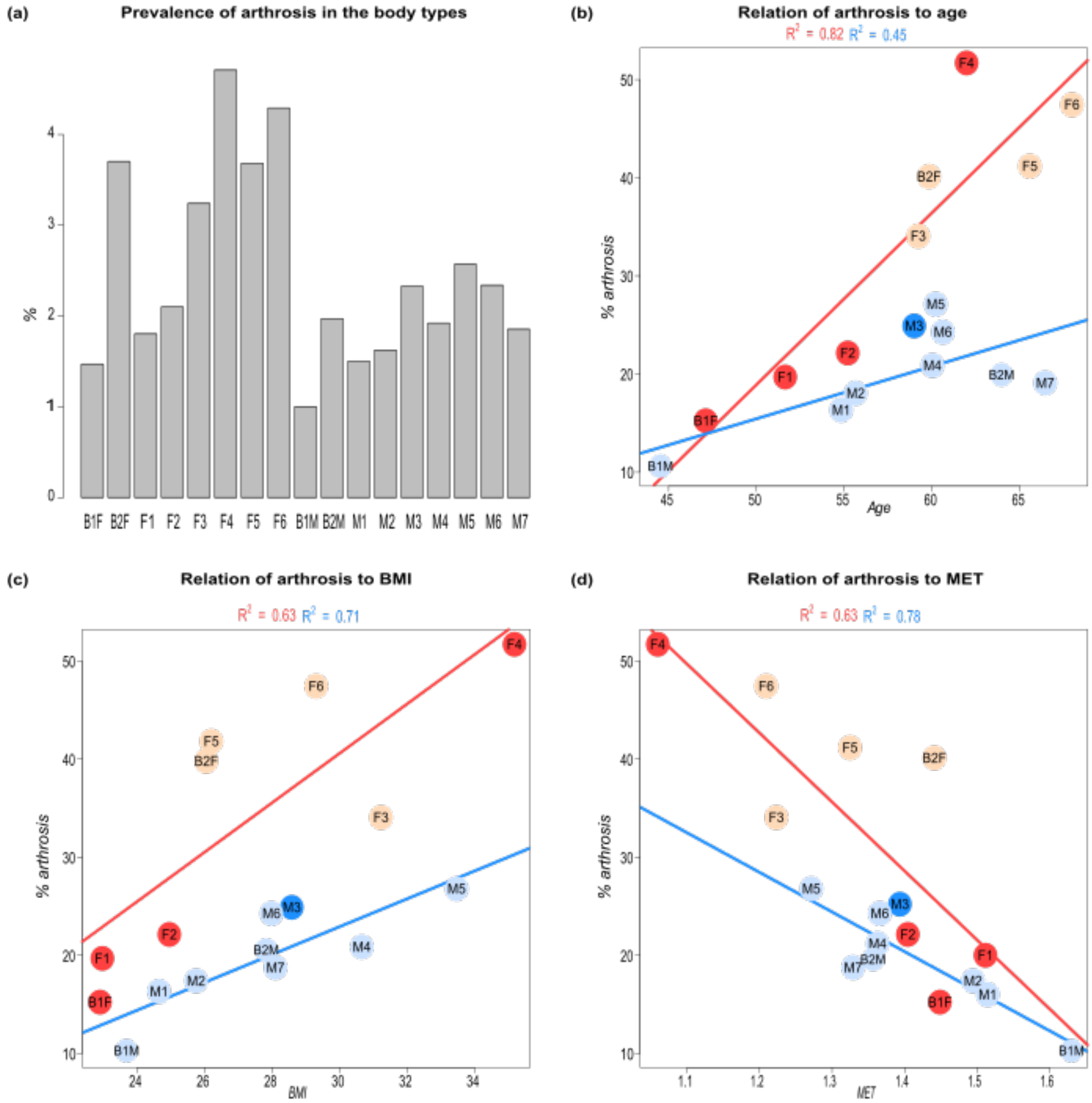
Also contrary to cardiovascular diseases, regression line of the parameters age, BMI and MET show steeper slopes for female body types (Figure 14 b - d). For the age model of female body types the strongest linear relation could be found with R^2 of 0.82 (Figure 14 b). Please note the clear successive increase of prevalence percentages beyond the age of 55. The male body types scatter around the regression line, which is also reflected in a lower R^2 of 0.45.

Both BMI regression lines are increasing, and both R^2 values indicate a reliable linear relation between BMI and the prevalence of arthrosis (Figure 14 c). The female body types are distributed in a wider range around the regression line compared to the more a narrow distribution of the male body types. The same characteristics could be found for the MET regression analyses, except that both graphs are decreasing (Figure 14 d). For both genders, R^2 models are showing similar characteristics.

The significant body types according to the logistic regression model are F1, F2, F4, and M3 (p-values < 0.05). Thereby, F4 and M5 are associated with higher arthrosis prevalence, F1 and F2 with lower prevalence for arthrosis. Age is a significant co-factor for both genders (p-value < 0.001), however BMI only significantly contributes to the model of the male body types (p-value < 0.001).

In summary, we observed a dependence of arthrosis prevalence from all three parameters considered, namely age, BMI and MET. The higher prevalence of arthrosis in female body types, especially beyond an age of about 55 years, agrees with previous studies. [77] A common risk factor of arthrosis is osteoporosis, which is more frequent among postmenopausal women and potentially driven by the change of hormone status. [80] We can also state that F4 and M5 exhibit the highest prevalence among the female and male body types, respectively. This view supports the assumption that body types F4 and M5 are accompanied by increased health risks for a wide range of morbidities.

Figure 14 Body type prevalence of arthrosis as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10.

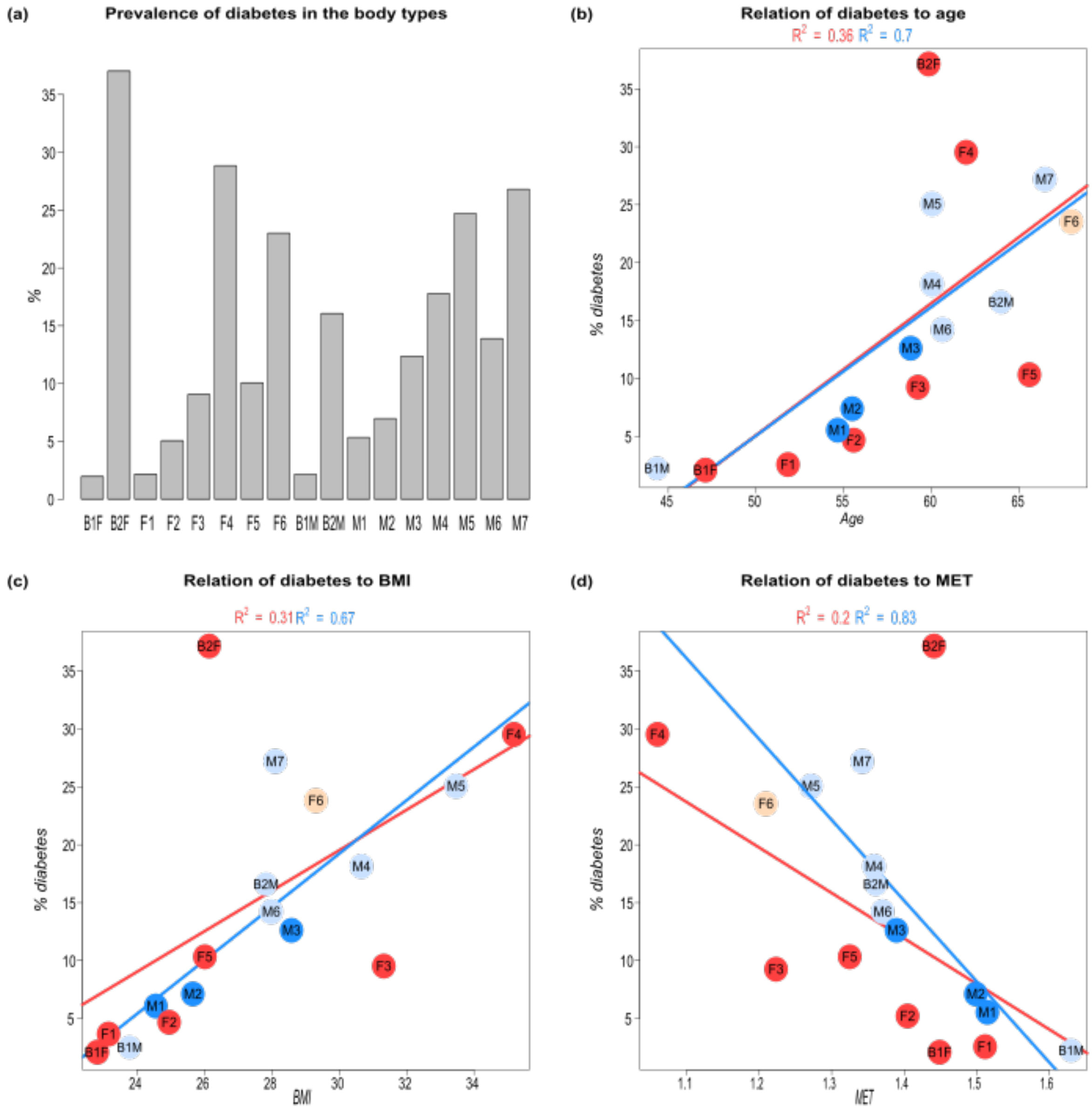


6.8 Diabetes

Diabetes is a major health issue in the western world, and accompanies the increasing frequency of overweight and obese people. Therefore, one particular aim of the LIFE study was to investigate the relation between diabetes predisposition, BMI, and the body types. [20, 38, 41, 56, 88]

The highest percentages of participants diagnosed with diabetes can be found in the older body types B2F (however with low sample number), F4, F6, M5, and M7 (Figure 15 a). Their prevalence is about 25%, which is more than five times higher than the prevalence in the younger body types F1, F2 and, M1. Interestingly, the older body types F5 and M6 show almost 15% lower prevalence than body types with similar age (F4 and F6, and M5 and M7, respectively). In general, no gender-specific dependence of diabetes prevalence could be seen.

Figure 15 Body type prevalence of diabetes diagnosis as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10.



When investigating the relation between age and diabetes, we find a larger scatter of the female body types resulting in lower coefficient of regression (R^2 of 0.35 vs. 0.70, see Figure 15 b). Several body types deviate from the regression line, in particular the female body types B2F, F4, and F5.

Regression analysis of the parameter BMI results in similar R^2 values, but notably the slope of the regression line for male body types is steeper (2.3 vs. 1.8, Figure 15 c). We can see a worse linear fit of the female regression line in terms of R^2, which is 0.31. When discarding the two outlying body types B2F and F3 from regression analysis, the coefficient of regression increases to R^2=0.56.

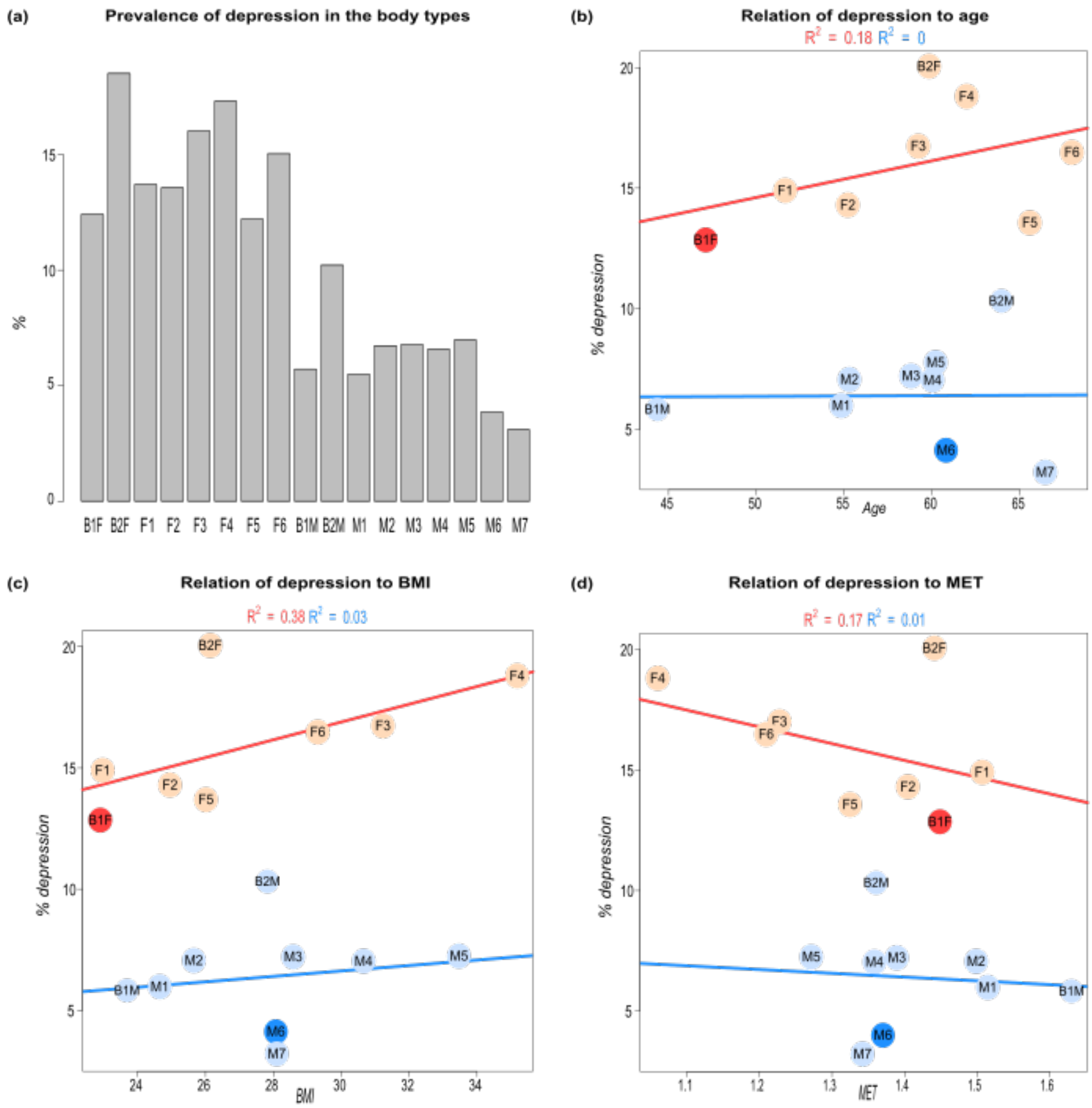
Regression analysis using MET as a predictor resulted in low regression for female body types (R^2=0.20), while the male body types show a good fit (R^2=0.83, Figure 15 d). Again, we can observe a bias in the regression analysis of female body types by the outlying body types namely B2F and F3. Hence, we removed them from the model, resulting in an almost perfect fit with R^2 of 0.96 and same slope as the male regression line (-68.6, data not shown).
In logistic regression analysis of diabetes prevalence, we see a number of significant body types contributing to prediction. Mostly all of the female body types are significant (p-values < 0.01), except for F6. Thereby F4 and B2F reveal positive coefficients and are associated with increased prevalence for diabetes, whereas the other female body types are associated with lower prevalence. Also the youngest male body types M1, M2, and M3 are related to lower disease prevalence (p-values < 0.05). Co-factors age and BMI are significant for both genders (p-values < 0.01).
In summary, male body types show linear relations to the parameters age, BMI, and MET. The linear relation for female body types is biased by the high prevalence of B2F and F4. However, most female body types are significant predictors in the logistic model, indicating strong association between diabetes and female body shapes. The oldest and other health risk body types show the highest prevalence for diabetes.

6.9 Depression

The incidence of depression and other psychiatric diseases has been growing in the last years. Consequently, the LIFE study considered depression as a civilization disease. [18, 21, 56, 94] In the overall study population, we have observed a strong difference between occurrence of depression in male and female participants (6% vs. 15%, see also Table 8), which is also reflected in the body type prevalence (Figure 16 a). The percentages in the female body types are at least twice as high as in the male body types, whereby B2F and F4 exhibit highest prevalence among women (about 17%), and B2M among men (10%). This data is basically in agreement with the recent literature in which the life time prevalence for depression in Germany is 12.3% for men and 25% for women. [70, 78] However, we observe slightly lower prevalence as the willingness to participate in a study is expected to be biased by a current depression.
In regression model using age as predictor, both genders showed no linear relation (Figure 16 b). This is suggested by the prevalence bar plot (Figure 16 a). As expected, the regression line for female body types is on a higher level, and slopes and regression of the models of both genders are negligible.
The characteristics of the regression lines for the BMI regression model are similar to the previous one (Figure 16 c). Neither is there any linear relation for male body types, as well as

only a low coefficient of regression for female ones (R² = 0.39) with slightly rising regression line. For the MET regression we further see no reliable linear relation to depression prevalence (Figure 16 d).

Figure 16 Body type prevalence of a previous or present depression as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of Figure 10 Prevalence of body types for hypertension .



In logistic model, body types B1F and M6 protrude as significant predictors, both associated with lower depression prevalence (p-values < 0.05). Co-factors are not significant (p-values > 0.05), except for age in the female (p-value < 0.01) participants. Notably, coefficient of the latter factor is negative, meaning that older women are associated to lower depression prevalence. This is unexpected because prevalence between 55 and 70 years is higher than in average population. [70]

These results show no or weak association between depression prevalence and age, BMI, MET, or body types. It is interesting that high BMI among women is the only, but weak, factor which is potentially related to increased depression incidence. The risk body types F4 and M5 exhibit also high prevalence of depression. This high prevalence in the health risk body types can potentially be an indicator for overall increased health risks in this body types, but also for increased depression predisposition due to the body shape and its impact on psychical constitution. [82]

6.10 Rheumatism

Rheumatism is a diverse group of diseases causing chronic pain in musculoskeletal system, especially in the joints [5, 48, 51]. Several forms of rheumatism are caused by autoimmune inflammation. As such, we expect no or only little association to anthropometric and activity parameters.

Most body types showed prevalence of about 5%, except F6 with a striking maximum of 9% (Figure 17 a). Rheumatism is more prevalent in the female body types than in the male ones. The body type B2F exhibit the lowest prevalence of all body types with no occurrences of rheumatism, supposedly caused by low sample number in this body type. Therefore this body type was excluded from the linear regression models which will be discussed below.

Regression lines of the parameter age are increasing with small slope for both genders (0.2 and 0.1 for female and male body types, respectively; Figure 17 b). We observe good linear fits with R^2 of > 0.5, which reflects the fact that rheumatism occurs more frequently in older body types. This linear relation is more pronounced for women than for men.

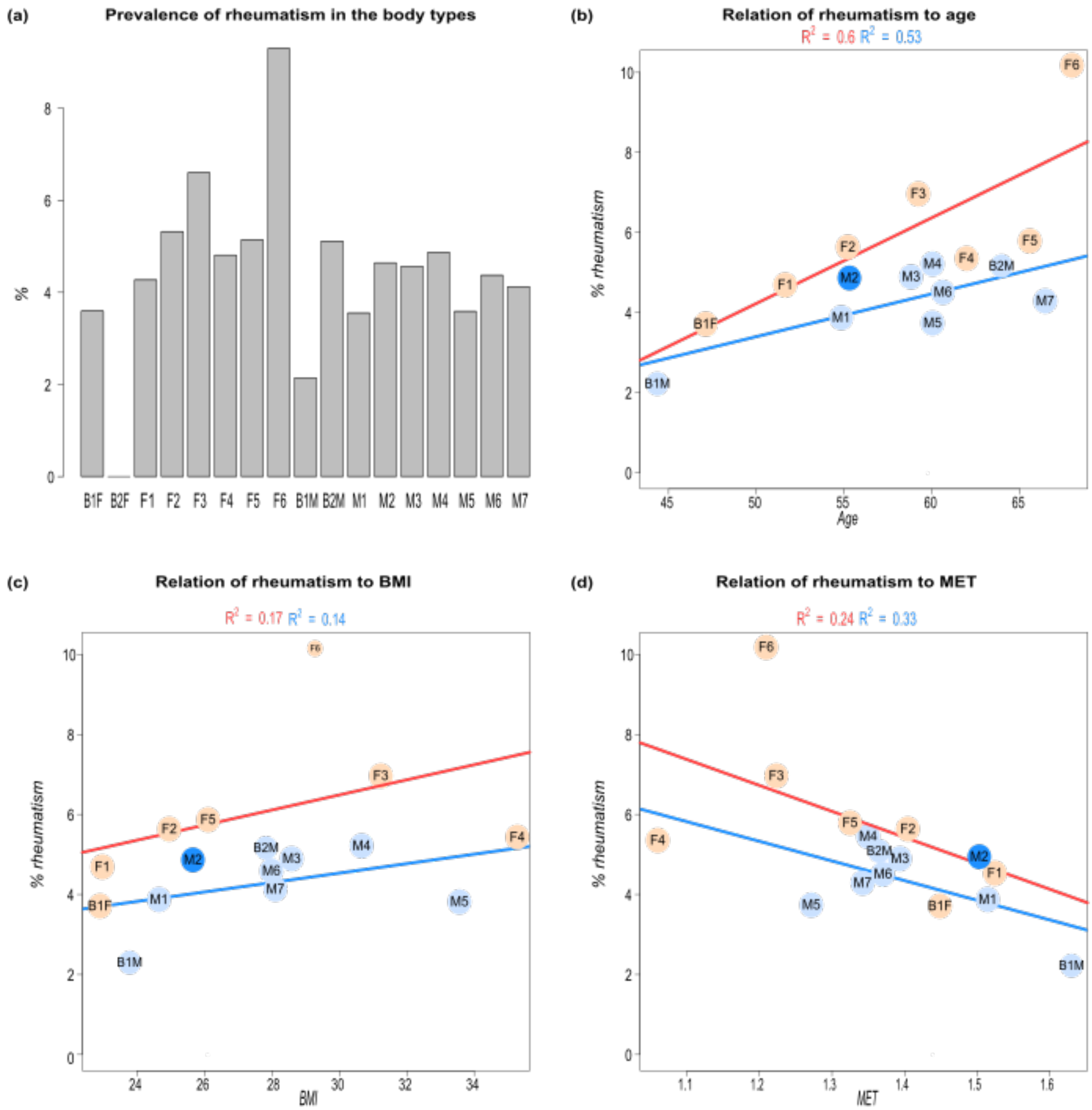
The BMI regression lines increase, but with low R^2 values (female body types 0.2, male 0.1, Figure 17 c). The body types with the highest distances from the regression lines are F4, F6, B1M, and M5, showing lower or higher rheumatism prevalence than expected for the mean body type age.

For the MET model, we basically found an inverse picture, with decreasing regression lines and the same outlying body types (Figure 17 d). The R^2 values are higher than in the BMI model, but still too low to consider a linear relation.

Application of logistic regression analysis resulted in only one significant predictor, which is body type M2. Although this is one of the youngest body types, men belonging to this body type show increased rheumatism prevalence. Possible reasons can be hardly identified due to the diverse causes of rheumatism. While age is a significant co-factor in the models of both genders (p-values < 0.001), BMI is not (p-value > 0.05). This underlines our findings from age and BMI linear regression models.

The health risk body types F4 and M5 exhibit prevalence slightly below average, supposing again that anthropometric and activity parameters have only minor influence on rheumatism predisposition.

Figure 17 Body type prevalence of rheumatism as bar plot (panel a), and as function of age (panel b), BMI (c), and MET (d). See caption of figure 10.



6.11 Disease prevalence and their relation to the body types

Merging together the findings from the subchapters above, we can state that there are mostly clear associations between age and the prevalence. Most diseases occur more commonly in older ages. Only for depression we found no relation for male participants, and even negative relation for female participants (logistic regression model), which means lower disease incidence in older age.

The slope of the regression line, i.e. the parameter coefficient in the model, reflects a correlation of this parameter on disease prevalence. Note that slopes are depending on both the parameter and the prevalence ranges. For age, strongest influence (steepest slope) for hypertension prevalence could be found. This can be explained by the large differences of prevalence in the age groups ranging from 17% up to 75% (Table 8).

BMI protrudes as a good predictor for some, but not all diseases (linear and logistic regression). Association between BMI and prevalence has been found for the diseases hypertension, hyperlipidaemia, and arthrosis. For male body types, also angina pectoris and diabetes are related linearly to BMI. For all diseases listed above, increasing BMI is accompanied by increasing disease prevalence. Considering MET, we mostly found results analogous to BMI, but with inverted relation: We observe decreasing prevalence with increasing physical activity as represented by MET. Most models showed linear relation of BMI and MET with only few exceptions (Table 9). Also, we found that cardiovascular diseases are associated to MET only for male body types in regression analyses, whereas no relations for female body types were found.

With regard to depression, no linear relation to anthropometrical (BMI, body types) or activity (MET) parameters could be observed. Only two body types significantly contributed to the logistic regression model (B1F and M6).

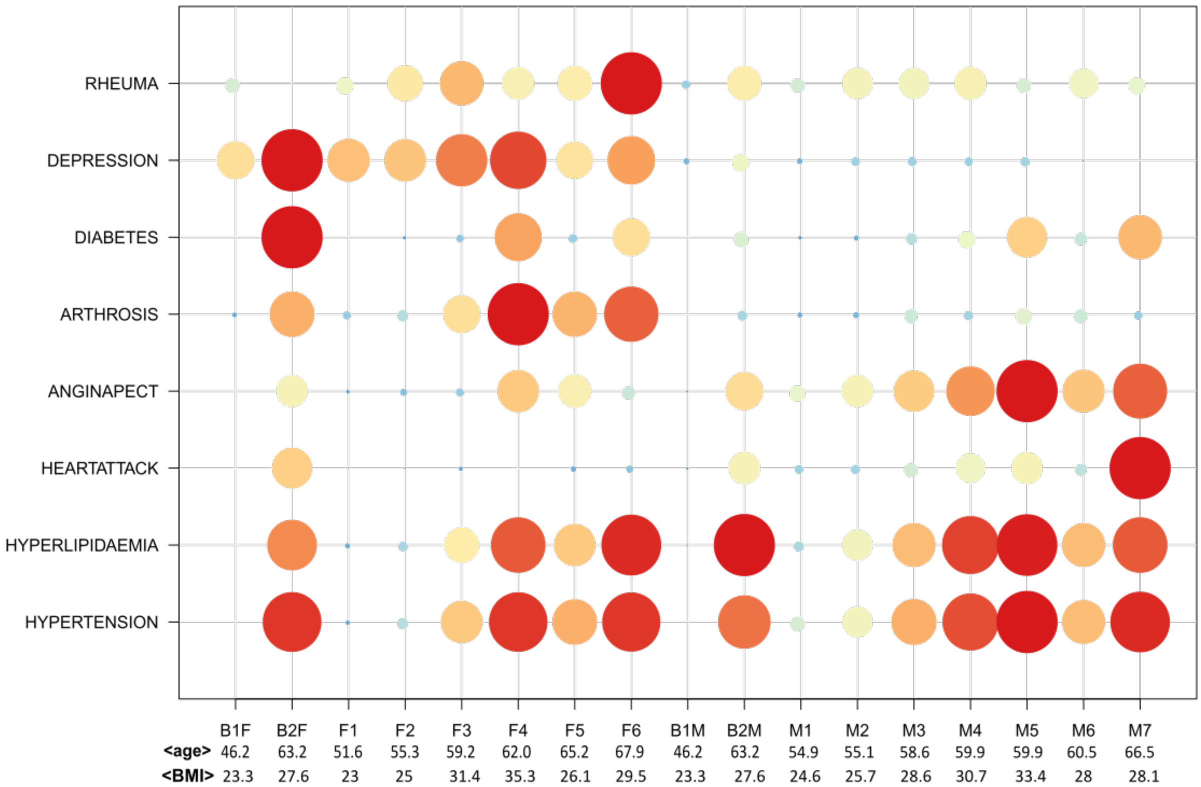
Youngest female body types F1 and F2 act ‘protectively’, as they significantly contribute to low prevalence for multiple diseases in the logistic regression models. (Figure 18) On the one hand, the youngest male body type M1 was identified as a significant contributor only for one disease (diabetes). On the other hand, M2 has more bivalent character: It is associated to lower diabetes prevalence, but also to increased hyperlipidaemia and rheumatism prevalence despite also collecting younger men of the study population. Oldest body types F6 and M7 did not contribute significantly to any of the disease prevalence. This can be explained by the fact that age was also included as (significant) co-factor in the logistic models. In consequence, these body types are not accompanied by further health risks apart from their age.

However, body types F4 and M5 are characterized by several health risks as discussed above, but they are also rarely significant in the models (Figure 18). We assume that the reason is similar and that inclusion of BMI as a co-factor represents the main risk factor of these body types.

Gender-unspecific B-body types showed mixed characteristics (Figure 18). Whereas B1 (in both genders) is 'protective' in some diseases, B2 was associated with increased prevalence. However, sample numbers in the B-body types are rather low, which limits these findings.

The predomination of different kind of disease in female or male body types is shown in Figure 18, e.g. rheumatism, depression and arthrosis in F-body types and heart attack as well as angina pectoris in M-Body types. A third tendency can be found in Figure 18 which is the higher prevalence of hypertension and hyperlipidaemia in older body types. These circumstances emphasize the legitimacy of our selection of diseases which covers most of reasonable etiologies with regard to the parameters age, BMI and MET.

Figure 18 Summary of disease prevalence in body types. Size of the circles scales with prevalence for each disease.



During the statistical analyses, different limitations emerged. Firstly, the distribution of the mean body type age was almost uniform for the female body types, but some male body types (especially M3 to M6) accumulated in a more narrow age range (see e.g., x-axis of Figure 9 a).

Secondly, there were outlining body types in the regression models, which could interfere with the R^2 values. In particular, B2F often deviated from the fit while only collecting few participants. Therefore, we applied regression models again after outlier removal in some cases, leading to more reliable results.

Thirdly, slopes in the linear regression analyses depend on the parameter and the prevalence ranges, which render comparisons between the parameters' models invalid. For the comparison of slopes in models of more and less frequent diseases, values of absolute prevalence needs to be included into consideration.

Finally, prevalence information was subsumed for the body type in the linear regression approach, reducing this information from all participants of a particular body type to one single percentage specification. Therefore, we included logistic regression model in the individual participant level for each disease, allowing to evaluate body type membership as a predictor in the model, and to maintain information richness.

In conclusion, we confirmed relations between health risk factors present in the body types and prevalence of several diseases. The evidence of causality is still pending, however follow-up of the LIFE study will provide novel longitudinal information, which will allow validating the findings of this thesis.

7 A holistic review of the body types in the LIFE study population

7.1 General aspects

In the previous chapters we have collected a lot of different information about the body types and have discussed them in the corresponding context. The following review will give a holistic overview of important body type characteristics, which have been provided by our analyses of anthropometrical data, activity parameters, and disease prevalence. Detailed information of the body types were taken from tables and figures in this thesis and from "**Novel anthropometry based on 3D-body scans applied to a large population based cohort**" by Löffler-Wirth et al. [38]

Figure 19 and Figure 20 show different body shape silhouettes, which were derived from 3D-body surface scanning. [38] For this, participants representative for each body type have been selected. We see that body types apparently differ in their body shape, e.g. lean and younger body types (F1, F2, M1, & M2), overweight and high risk body types (F4 and M5), as well as body types of the oldest participants (F5, F6 and M7).

7.2 Gender-unspecific body types B1 and B2

The B-body types B1 and B2 collect participants with body measures that did not match the female (F-) or male (M-) body types. Thereby the B-body types represent in total 610 participants, whereas B2F (female participants in B2) is characterized by a small group size of only 27 participants. [38]

Women contribute the major part of **B1** (69%). B1 is by far the youngest body type with a mean age of 46 years which is 15 years below the mean age of B2. The body type B1 is shaped thin and tall (on average 5cm taller than B2), which causes lower values in the index parameters like BMI and WHtR. Participants in B1 are slightly more active than those in B2, and also more active than other body type's participants. Regarding the prevalence of the diseases investigated, B1 shows lower or lowest values in most diseases. Overall, B1 is a characteristic body type of young, lean and active women with only weak disease predisposition.

Contrary, **B2** is composed of mainly male participants (about 80%), and it is of higher age than B1. Remarkably, B2 participants are smaller than B1's and other body type's participants. Moreover they show high WTH values overall. The B2 body type comprises participants with low physical activity and long sleeping duration showing mostly high or even highest disease predispositions.

In summary, B1 can be considered as a younger, rather feminine and health-conscious body type, whereas B2 is the opposite: an older, masculine body type with increased health risks.

7.3 Female body types

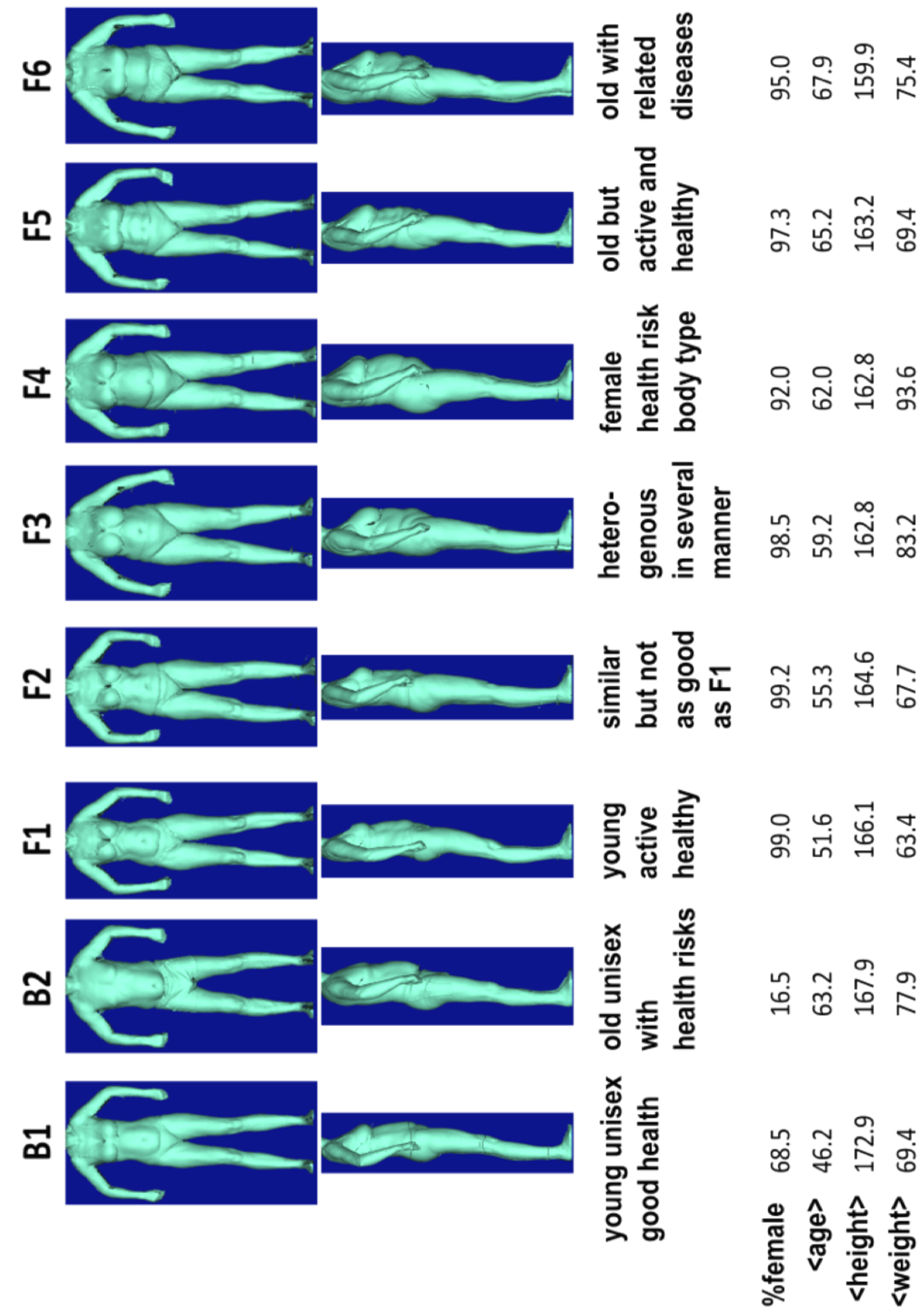
The gender-unspecific body types comprise participants from both genders to a considerable amount. In turn, female (F-) body types exclusively collect women (on average 97%). Mean age thereby ranges from 51.6 in F1 to 67.9 in F6. [38]

In body type **F1,** we find young and active women being characterized by a mean weight which is below the average of all participants and lower values in anthropometric indices BMI, WTH and WHtR. F1 is containing the highest number of participants among the F-body types. However, parameters, in particular weight, are basically tending to be specific in terms of narrow distributions. Increased activity of the F1 participants was represented by high MET values and (on average) longest time spent in moderate intensity activities of all F-body types (Figure 5). This also implies lowest prevalence of all the diseases presented here.

With regard to anthropometrical and activity parameters the body types **F2** is similar to F1. Nevertheless, F2 is slightly older (about 4 years) and shows higher values in weight, BMI, and WTH values than B1, but is still on a relatively low level. Accordingly, we observed slightly higher disease prevalence in F2.

F3 is a more heterogeneous body type which can be derived from mostly collective distributions of the anthropometrical parameters. It is noteworthy, that nearly all participants of this body type show BMI values higher than 25. This means that the F3 body type represents over-weight and obese women. The related health risk property is accompanied by low levels of activity (MET and time in moderate activity).
Health risks of this body type are not only reflected in high BMI (and accordingly WTH and WHtR indices) and low activity, but also disease prevalence is markedly high given that F3 is the third-youngest female body type with 59.2 years on average. Interestingly, F3 associates with lower prevalence of diabetes, which is difficult to explain applying the examined parameters. We have to suppose that there are other protective, e.g. genetic or metabolic, factors in this body type.

Figure 19 Body surface scan images of participants' representative for B-and F-body types.



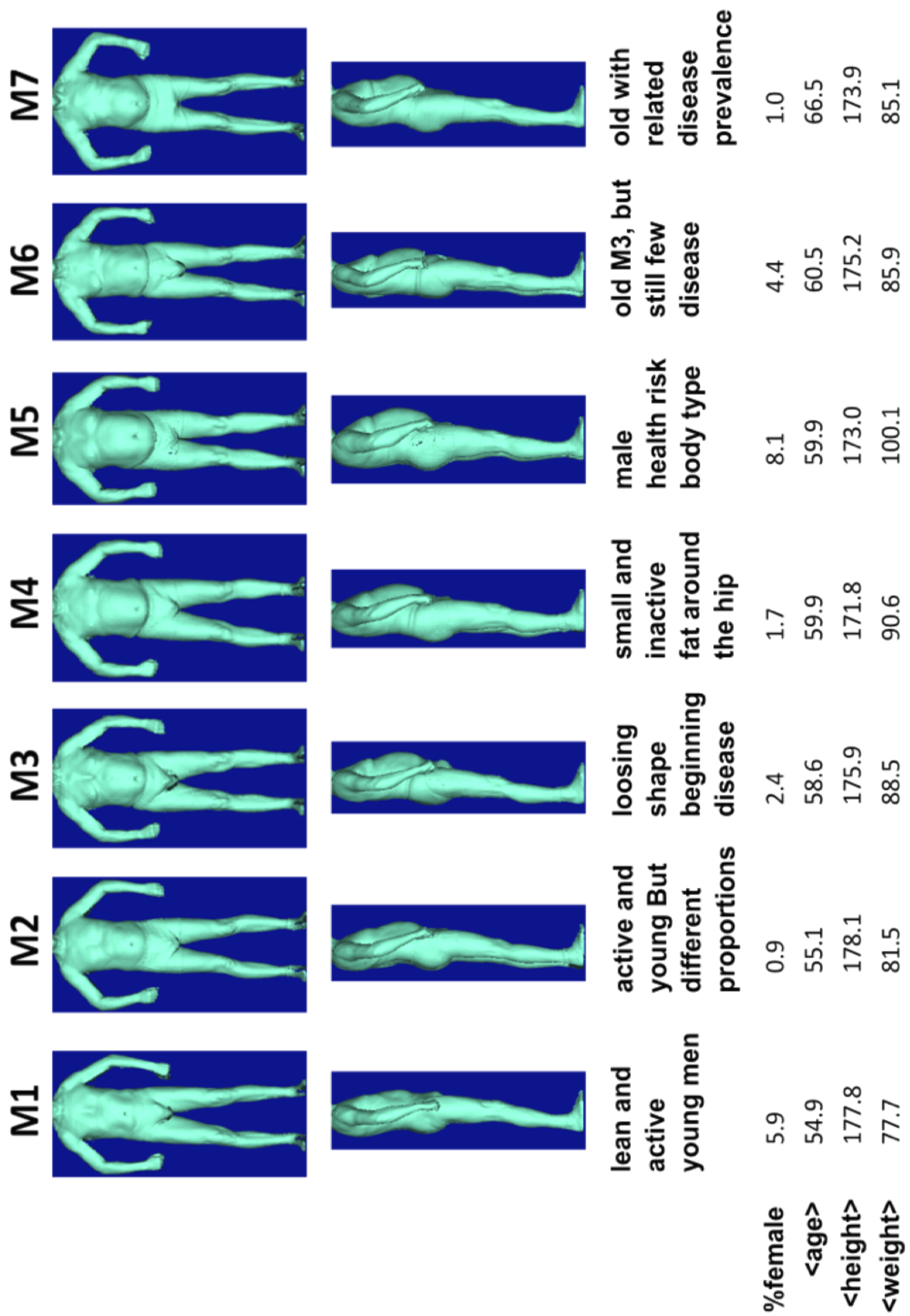
F4 shows even higher values regarding anthropometry and activity: it collects the heaviest female participants with highest BMI, WTH and WHtR indices among all female body types. In particular, more than 92% of the individuals in F4 are obese (BMI ≥ 30). Additionally, they have, by far, the lowest MET scores. Hence this is supposed to be the most 'unhealthy' female body type with the highest health risks. This confirms the assumption that F4 exhibits highest values in all F-body types. Only in the cardiovascular diseases, oldest-age body type F6 shows even higher prevalence. Note that, with 112 participants, F4 is the smallest of all F-body types.

The second-oldest female body type is **F5** (65.2 years on average). The anthropometric parameters are similar to those in F3 and are often located in an intermediate range. MET is lower than in F1 to F3, attributable to the older age. Importantly, physical activity (MET and time in moderate intense activity) is on a higher level than expected in population of this age. Also, weight and BMI are lower than in the reference age group. Therefore, we conclude that F5 represents body shape of lean and active older women accompanied by lower disease prevalence compared to F3 and F4. Nevertheless, we observed relatively high prevalence especially of age-related diseases (cardiovascular diseases, hypertension, and hyperlipidaemia) compared to the younger F-body types.

F6 is the oldest female body type (67.9 years). It is characterized by relatively high BMI and WTH values compared to the reference age group and to the younger F5 body type. We showed that this body type includes the majority of female participants older than 70 years of age, which also leads to increased prevalence of age-related diseases. In particular, F6 shows highest percentages of participants with hypertension, previous hyperlipidaemia diagnosis, and myocardial infarction. Prevalence of angina pectoris is, in turn, lower than in F4 and F5 but still higher than in the younger F-body types. Summarizing, F6 is the oldest female body type characterized by a small, rather fragile body shape, a low degree of physical activity and a high prevalence of age-related diseases. Compared to F5, F6 shows higher risk of disease among the old female body types.

In general, the F-body types have systematically lower prevalence of cardiovascular diseases and higher prevalence of depression as discussed above. Thereby, F1 is the youngest, most active and 'healthiest' body type. F4 represents a health risk body type, and F5 as well as F6 are complementary body types of the oldest female participants and are associated with higher activity and higher disease prevalence, respectively.

Figure 20 Body surface scan images of participants' representative for M-body types.



7.4 Male body types

The male (M-) body types are nearly exclusively containing men (on average 97%, analogous to F-body types). The mean age of the M-body types ranges from 54.9 to 66.5, which is comparable to the F-body types. According to the previous subchapter, we could identify more healthy body types and body types with higher disease prevalence among the male participants:

The **M1** body type reveals the highest number of participants among the M-body types (1321 individuals). A possible effect of this is that M1 tends to be collective for various parameters, e.g. age, body height, and MET. The body type M1 is characterized by the tallest body height and lowest weight among the M-body types, and by the lowest BMI and WTH values. Furthermore, we could find low sleeping durations and the highest MET values. M1 exhibits low prevalence in almost each of the disease presented. M1 is consequently the lean and active body type of young men, in analogy to F1 in women.

The **M2** body type exhibits low values of BMI and WHR, as well as high MET values. In general, distributions of these indices and the activity parameters are almost identical to M1. The body types M1 and M2 have previously been described as a young masculine body shape with long extremities or a long upper body, respectively, which is confirmed by the findings in this thesis. [38] Also with regard to disease prevalence we found similar percentages in these body types. Thereby, M2 shows slightly increased values of disease prevalence which are nevertheless second-lowest among all M-body types with regard to most diseases. Despite these low values, M2 has been found to be significantly associated with increased hyperlipidaemia and rheumatism prevalence in the age-adjusted logistic regression. For depression, which was shown to be nearly independent of age, M2 reveals highest prevalence, which is on the same level as in body types M3 to M5 (about 7%, 2% more than M1).

M3 (and further M4) follow the trend of increasing weight, BMI and WTH while decreasing MET as discussed for M2. In particular, BMI and WTH are significantly higher than in the corresponding age reference group. However, MET is lower. Contrary to M1 and M2, the majority of participants in M3 is overweight (BMI $\geq$ 25 in 96% of M3 participants). These risk factors are also reflected in increased disease prevalence, in particular hypertension, hyperlipidaemia, cardiovascular diseases, and arthrosis. For the latter, we observe second-highest percentage in the M-body types (about 25%), and M3 has additionally been identified a significant predictor in the logistic regression model of arthrosis.

The body type **M4** represents small and relatively inactive people with only few hours of sleep. We can see highest WTH values, which are on the same level as in the health risk body type M5. A reason for the high WTH is the accumulation of fat around the hip. [38] Also the small body height of M4 participants is noteworthy: This body type collects the smallest men from the study population, although there are older body types which are supposed to be smaller due to decrease of body height accompanying the normal ageing process. M4 shows high disease prevalence, with most values ranging around those of M3 and M5. For arthrosis however, we find lower percentage in M4 than in M3 (about 5% less), which is caused by the high prevalence in M3 as discussed above. In general, M4 can be considered as an intermediate body type with most anthropometrical, activity and prevalence characteristics between those of M3 and M5.

In **M5** we find the heaviest and most inactive people among the M-body types. In addition with 84% of obese participants (BMI ≥ 30) it is considered as one of the health risk body types. For weight and BMI, we see highest values in the male body types, and the lowest for step number, time spent in moderate intensity activity and MET. These characteristics are highly significant in comparison to the age reference groups (p-values < 0.001) and have negative effect on health. Consequently, maximum prevalence for almost all diseases could be found in M5. These findings underline that M5, similar to F3 and F4 implies marked health risks, which is to be confirmed in future longitudinal assessment of the LIFE study population.

M6 is the second oldest body type of male participants and shows intermediate anthropometrical and activity parameters similar to M3. In comparison to the oldest male body type M7 we find, on the average, 2cm taller participants with lower WTH but almost identical BMI and MET values. Also, with respect to disease prevalence, parallels to M3 rather than to M7 are seen. M6 disease prevalence is almost identical to those of M3 and virtually consistently lower than those of health risk body type M5 and old male body type M7. Strong differences to the latter body types can be found for hypertension, hyperlipidaemia and the cardiovascular diseases, and especially for diabetes. We can find more than 10% less prevalence than in M5 and M7. We conclude that the lower disease prevalence of M6 is related to the fat distribution of the participants: Despite, BMI is similar to M3 and M7 and WTH is lower, thus indicates less visceral fat. To sum up, we found that the body type M6 is characterized by older but slightly more active and healthier participants, and additionally that M6 represents an older equivalent to M3.

The old male body type **M7** is characterized by mainly age-related traits. Small body height is accompanied by high WTH, reflecting the transition of older people into apple-like body shape. [103] The mean weight of 85.1kg is lower than for younger body types M3 to M6 and can also be attributed to aging. M7 shows high prevalence of multiple diseases. In particular, with about 12% myocardial infarction prevalence is almost twice the value of the second highest prevalence in M5. Arthrosis and depression showed only little relation to age. Furthermore, the prevalence of these diseases is lower in M7 than in M5 and M6. Note that M7 collects the lowest number of participants of all body types (98 individuals). Taken together, M6 and M7 represent the oldest men in the study population, whereby participants in M6 are more active and healthier than participants in M7.

Summarizing, body types M1 to M3 represent younger male participants with continuously increasing BMI and disease prevalence, and decreasing physical activity. M4 and M5 include exclusively overweight and obese participants, whereby M5 shows high disease prevalence and is the major health risk body type for men. M6 and M7 are body types of oldest male participants which are more active or more affected by diseases, respectively.

8 Summary and Conclusion

In this thesis we presented data on anthropometry, actometry and medical anamnesis collected in the frame of the LIFE ADULT population study. After discussing anthropometrical and activity parameters stratified by age and gender, we introduced previously defined body types for this study population, and transferred the data into this context. We found that physical activity is related to diverse anthropometric measures, and also diversifies in the body types. It is crucial to consider aging as a fundamental factor driving changes in body shape and physical exercise, and leading to accumulation of diseases in participants' medical history. Therefore, we compared the participants of the different body types to reference age groups. This approach delivered several insights into body type characteristics which are de-facto adjusted for age. Additionally, we investigated age-related heterogeneity within the body types for different parameters. It turned out that most body types are consistent in relation to the other body types along the respective age range covered. Next, we employed data about previous occurrence of selected diseases provided by the study's questionnaires. By applying two regression approaches we were able to identify body type specifics as well as age related diseases. Finally, findings from anthropometric and activity data analysis, and from the disease prevalence were combined to give a holistic review of the LIFE body types.

Therewith, this thesis supplemented the previous body type definition, which was based on body scanning data solely, with novel and comprehensive characterization and comparisons beyond anthropometry. Health risk body types were identified showing high BMI and low MET values: F4, M5, and, to a lesser degree, F3 are indicated by several risk factors, and revealed increased prevalence of a multitude of diseases. With this, we demonstrated the relevance of the body typing approach in the context of public health. However, it is necessary to validate our findings by tracing changing body shapes upon aging and establishing causal relations. The follow-up of the LIFE ADULT and the German National Cohort study (NAKO) will provide additional data which will be used for these purposes. Our journal article "**The ageing human body shape**" supplements the findings of this thesis and opens a perspective of the body typing approach with regard to application in healthcare and is attached as Appendix B. In this article, the ageing process is discussed in the context of anthropometry, physical activity, and disease predisposition as represented by myocardial infarction prevalence.

The body types, together with their comprehensive review provided in this work, offer several opportunities for use in medical and health context. It is possible to classify the body type of an individual patient by scanning with a mobile 3D-body scanner, or, with limited reliability, by manual anthropometry. This might improve estimation of risk factors based on a combination of individual and body type related characteristics. Therapy or prevention programs for certain body types could be developed faster to focus on their specific needs, and to optimize selection and intensity of exercises. A more controversial example in the economic context could be adapted fees for health insurance or costs for medication. The adaption on the body type could lead to a more effective distribution of resources and money and to a more individual health care system compared with the recent standards.

Concluding, this work provides a fundamental contribution for understanding body shapes and their implication on health, and hence is another step towards individualized medicine.

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Appendix A Regression analysis of body measures towards MET.

1.4 MET = median MET value, See 4.3 Body measures associated with activity parameters and Figure 3.

Body measure	Type	≤ 1.4	> 1.4	R^2
MIDDLE_HIP	circumf.	107.55 ± 10.31	96.39 ± 8.33	0.39
WAISTBAND_DEPTH	distance	27.35 ± 3.56	23.81 ± 2.63	0.36
BUTTOCK_DEPTH	distance	29.56 ± 3.93	26.01 ± 2.55	0.34
HIGH_HIP_GTH	circumf.	105.05 ± 10.55	94.38 ± 9.08	0.34
WAISTBAND	circumf.	100.91 ± 9.78	91.06 ± 8.3	0.33
MAX_BELLY_CIRC	circumf.	105.16 ± 10.77	94.26 ± 9.37	0.33
BUTTOCK_GTH	circumf.	108.98 ± 8.91	101 ± 6.11	0.33
BELLY_DEPTH	distance	29.64 ± 4.3	25.44 ± 3.61	0.32
MAX_BELLY_DEPTH	distance	29.7 ± 4.28	25.51 ± 3.58	0.32
BREAST_DEPTH	distance	30.16 ± 3.12	27.15 ± 2.67	0.32
HIP_DEPTH	distance	29.29 ± 4.51	25.19 ± 3.23	0.32
BELLY_CIRC	circumf.	104.02 ± 10.91	93.37 ± 9.63	0.31
WAIST_GTH	circumf.	101.13 ± 12.2	88.97 ± 11.51	0.3
HIP_GTH	circumf.	109.96 ± 8.94	102.62 ± 6.13	0.29
BMI	index	29.14 ± 5.07	24.66 ± 4.03	0.28
WHtR	index	0.6 ± 0.09	0.52 ± 0.08	0.28
HIGH_WAIST_GTH	circumf.	98.72 ± 12.39	87.57 ± 11.44	0.25
TORSO_WTH_WAIST	distance	47.36 ± 6.93	41.23 ± 6.22	0.25
BUST_CHEST_GTH	circumf.	108.41 ± 9.85	99.84 ± 9.05	0.25
BUST_CHEST_GTH_HZ	circumf.	109.32 ± 9.77	100.91 ± 8.84	0.24
BUST_PT_T_NECK_R	distance	31.54 ± 2.67	29.43 ± 2.28	0.23
CROTCH_LTH_AT_WB	distance	69.45 ± 6.35	65.44 ± 4.25	0.18
CROTCH_LTH_AT_WB_A	distance	69.45 ± 6.35	65.44 ± 4.25	0.18
KNEE_GTH_L	circumf.	40.74 ± 3.35	38.36 ± 3.52	0.17
WT	weight	82.8 ± 14.87	72.47 ± 13.35	0.17
KNEE_GTH_R	circumf.	40.45 ± 3.37	38.05 ± 3.77	0.16
UNDERBUST_CIRC_HZ	circumf.	98.8 ± 11.69	90.76 ± 11.19	0.15
WTH_ARMPITS	distance	47.21 ± 5.82	43.81 ± 4.59	0.13
NECK_DEPTH	distance	12.23 ± 1.73	11.15 ± 1.71	0.12
CALF_GTH_L	circumf.	39.02 ± 3.32	37.27 ± 2.63	0.12
THIGH_GTH_R_HZ	circumf.	57.96 ± 5.54	55.31 ± 4.12	0.11
CALF_GTH_R	circumf.	38.97 ± 3.32	37.25 ± 2.68	0.11
THIGH_GTH_L_HZ	circumf.	57.88 ± 5.4	55.24 ± 4.26	0.11
ACROSS_FRONT_WTH	distance	43.4 ± 4.5	40.79 ± 3.96	0.11
WAIST_BUTTOCK_HT_R	distance	18.69 ± 2.24	19.9 ± 2.02	0.11
UP_ARM_GTH_R	circumf.	31.26 ± 3	29.58 ± 2.71	0.11
WAIST_BUTTOCK_HT_L	length	18.65 ± 2.22	19.84 ± 1.97	0.1
WAIST_T_HIGH_HIP_B	distance	5.08 ± 1.98	6.13 ± 1.72	0.1
MIN_LEG_GTH_L	circumf.	24.28 ± 2.06	23.22 ± 1.69	0.1
CR_SHOULDER_O_NECK	distance	45.25 ± 3.4	43.38 ± 3.13	0.1
MID_NECK_GTH	circumf.	39.99 ± 4.49	37.46 ± 4.32	0.1
CROTCH_LTH_R	distance	42.2 ± 3.17	40.7 ± 2.85	0.09
UP_ARM_GTH_L	circumf.	31.24 ± 3.06	29.63 ± 2.94	0.09
WRIST_GTH	circumf.	17.61 ± 1.44	16.79 ± 1.39	0.09
HIP_THIGH_GTH	circumf.	100.25 ± 6.27	97.56 ± 5.08	0.09
WAIST_T_BUTTOCK	distance	18.84 ± 2.22	19.92 ± 1.95	0.09
CR_SHOULDER	distance	49.13 ± 3.75	47.2 ± 3.61	0.09

NECK_AT_BASE_GTH	circumf.	44.84 ± 4.84	42.31 ± 4.53	0.09
MIN_LEG_GTH_R	circumf.	24.17 ± 2.03	23.18 ± 1.75	0.08
HEAD_HT	length	22.94 ± 1.4	23.64 ± 1.36	0.08
ELBOW_GTH_R	circumf.	28.24 ± 2.44	26.96 ± 2.48	0.08
ELBOW_GTH_L	circumf.	27.98 ± 2.4	26.8 ± 2.41	0.08
NECK_R_WAIST_OV_BL	length	47.29 ± 2.56	46.13 ± 2.37	0.07
WHR	index	92.81 ± 11.54	86.89 ± 12.11	0.07
DIST_CROTCH_WAISTBAN	distance	25.37 ± 2.32	24.44 ± 1.88	0.07
TOT_TORSO_GTH	circumf.	172.11 ± 11.1	167.4 ± 10.87	0.06
CROTCH_LTH	length	83.46 ± 7.59	80.38 ± 7.13	0.06
NECK_DIAM	distance	13.55 ± 1.7	12.88 ± 1.46	0.05
HIP_HT	length	85.88 ± 6.26	83.36 ± 6.3	0.05
ABSI	index	0.08 ± 0.01	0.08 ± 0.01	0.04
AC_BACK_WTH_AL	distance	40.51 ± 3.8	39.1 ± 3.96	0.04
AC_BACK_WTH	distance	41.12 ± 3.7	39.83 ± 3.54	0.04
DEV_WB_FROM_WAIST_B	distance	-4.45 ± 3.68	-5.62 ± 3.25	0.04
UP_ARM_DIAM_L	distance	11.35 ± 1.62	10.81 ± 1.79	0.04
CROTCH_LTH_F	distance	41.26 ± 5.02	39.65 ± 4.74	0.04
SIDE_UP_TORSO_LTH_R	length	22.97 ± 3.26	23.82 ± 2.62	0.03
FOREARM_GTH_L	circumf.	27.01 ± 2.49	26.17 ± 2.54	0.03
SHOULDER_WTH_R	distance	15.69 ± 1.99	15.14 ± 1.65	0.03
UP_ARM_DIAM_R	distance	11.43 ± 1.61	10.95 ± 1.8	0.03
FOREARM_LTH_R	length	24.76 ± 3.13	25.55 ± 2.75	0.03
IN_LEG_ANKLE_L	length	67.99 ± 4.62	69.22 ± 4.46	0.03
DIST_WAIST_KNEE	length	59.33 ± 3.99	60.4 ± 3.78	0.03
DIST_NECK_T_HIP	length	58.57 ± 3.98	59.57 ± 3.71	0.03
INSEAM_L	length	75.45 ± 4.95	76.7 ± 4.78	0.03
FOREARM_GTH_R	circumf.	27.41 ± 2.62	26.55 ± 2.65	0.03
CROTCH_HT	length	74.25 ± 5.03	75.48 ± 4.91	0.02
HT_SHOULDER_BLADES	length	127.27 ± 8.16	129.35 ± 7.87	0.02
ANKLE_GTH_L	circumf.	27.58 ± 2.72	26.8 ± 2.86	0.02
SHOULDER_WTH_L	distance	15.5 ± 1.95	15 ± 1.55	0.02
SIDE_UP_TORSO_LTH_L	length	23.49 ± 3.22	24.23 ± 2.57	0.02
BREAST_HT	length	120.42 ± 8.4	122.37 ± 8.08	0.02
IN_LEG_ANKLE_R	length	68.3 ± 5.27	69.45 ± 4.89	0.02
FOREARM_LTH_L	length	24.69 ± 3.03	25.39 ± 2.63	0.02
ANKLE_GTH_R	circumf.	28.13 ± 2.49	27.45 ± 3.05	0.02
WAISTBAND_F_HT	length	96.5 ± 5.61	97.64 ± 5.17	0.02
ARM_LTH_R	length	56.02 ± 4.8	56.91 ± 4.65	0.02
INSEAM_R	length	75.84 ± 6.23	76.88 ± 5.09	0.01
ARM_LTH_L	length	55.88 ± 4.66	56.67 ± 4.52	0.01
SIDESEAM_WAIST_R	length	106.86 ± 6.68	107.97 ± 6.45	0.01
DIST_NECK_KNEE	length	99.57 ± 5.79	100.47 ± 5.68	0.01
SCAPULA_HT_2	length	129.65 ± 6.72	130.72 ± 6.86	0.01
HT	length	169.27 ± 8.89	170.68 ± 9.07	0.01
SIDESEAM_WAIST_L	length	106.8 ± 6.68	107.88 ± 6.43	0.01
NECK_R_T_WAIST_B	length	46.12 ± 3.25	45.51 ± 3.29	0.01
ANKLE_HT	length	7.45 ± 0.39	7.51 ± 0.4	0.01
DEV_WB_FROM_WAIST_S	distance	-6.67 ± 4.47	-7.35 ± 4.01	0.01
NECK_L_T_WAIST_B	length	46.31 ± 3.25	45.7 ± 3.27	0.01
NECK_F_T_WAIST	length	35.48 ± 2.63	35.08 ± 2.33	0.01
HEAD_CIRC	circumf.	59.55 ± 1.84	59.29 ± 1.77	0.01
WAIST_HT	length	106.13 ± 6.73	107.08 ± 6.6	0.01
NECK_HT_FRONT	length	138.95 ± 7.93	140.04 ± 8.03	0.01
WB_BUTTOCK_HT_R	length	12.04 ± 3.51	12.58 ± 3.4	0.01
NECK_WAIST_C_BACK	length	42.24 ± 2.71	41.8 ± 2.74	0.01

WB_BUTTOCK_HT_L	length	12.06 ± 3.46	12.56 ± 3.37	0.01
NECK_HT	length	146.33 ± 8.41	147.11 ± 8.45	0
HIGH_WAIST_HT	length	108.49 ± 6.45	109.1 ± 6.39	0
WTH_THIGH_L	distance	36.1 ± 3.01	35.85 ± 2.86	0
ARM_LTH_T_NECK_R	length	71.71 ± 4.75	72.06 ± 4.85	0
SIDESEAM_3D_WD_R	length	100.21 ± 5.12	100.61 ± 4.89	0
SIDESEAM_R	length	100.24 ± 5.11	100.64 ± 4.89	0
WTH_THIGH_R	distance	36.17 ± 3.01	35.93 ± 2.87	0
SIDESEAM_3D_WD_L	length	100.19 ± 5.12	100.54 ± 4.88	0
ARM_LTH_T_NECK_L	length	71.39 ± 4.75	71.67 ± 4.78	0
DIST_WAISTBAND_HIP	distance	2.49 ± 1.68	2.43 ± 1.66	0
NECK_AC_BACK_WTH_AL	length	15.96 ± 3.04	15.72 ± 2.75	0
SIDESEAM_L	length	100.25 ± 5.11	100.59 ± 4.88	0
SIDESEAM_ANKLE_R	length	92.84 ± 4.84	93.16 ± 4.6	0
WAISTBAND_HT	length	99.62 ± 5.13	99.93 ± 4.9	0
SIDESEAM_ANKLE_L	length	92.84 ± 4.83	93.12 ± 4.59	0
UP_ARM_LTH_R	length	31.25 ± 2.34	31.35 ± 2.42	0
SHOULDER_ANGLE_L	angle	23.8 ± 3.72	23.64 ± 3.58	0
MAX_BELLY_CIRC_HT	length	102.67 ± 6.52	102.13 ± 6.54	0
UP_ARM_LTH_L	length	31.19 ± 2.32	31.26 ± 2.36	0
SHOULDER_ANGLE_R	angle	24.26 ± 3.86	24.09 ± 3.95	0
DIST_AC_B_WTH_WAIST	length	25.92 ± 3.67	25.71 ± 3.2	0
DEV_WB_FROM_WAIST_F	length	-10.34 ± 6.15	-9.98 ± 5.43	0
KNEE_HT	length	46.8 ± 3.01	46.67 ± 3.04	0
BUTTOCK_HT	length	87.79 ± 5.65	87.56 ± 5.71	0
WAISTBAND_B_HT	length	101.77 ± 5.22	101.57 ± 5.09	0
ARM_LTH_T_NECK_B_R	length	78.79 ± 5.04	78.73 ± 5.13	0
DIST_WAISTBAND_KNEE	length	54.97 ± 2.95	54.88 ± 2.8	0
BELLY_CIRC_HT	length	102.58 ± 6.16	102.44 ± 6.23	0
DIST_WAISTBAND_BUTT	length	13.97 ± 2.71	13.97 ± 2.64	0
ARM_LTH_T_NECK_B_L	length	78.37 ± 5.01	78.24 ± 5.09	0

Appendix B The ageing human body shape

The ageing human body shape

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Abstract

Three-dimensional whole body scanning is an emerging technology for anthropometric assessment of the ageing human body shape to study health risk factors. We here applied a novel body typing concept to describe the diversity of body shapes in an ageing population and its association with physical activity.

Ageing results in reshaping of female and male bodies despite the diversity of body types observed. Slim body shapes remain slim and partly tend to become even more lean and fragile while obese body shapes remain obese. Female body shapes change more strongly than male ones. Physical activity is inversely related to the BMI and decreases with age. Paradoxically, obese and 'inactive' body types do not show increased prevalence of myocardial infarctions in men and, especially, women.

Stratification of ageing human body shapes into Life Course trajectories is a step towards personalized anthropometry to predict lifetime risks.

Introduction

Three-dimensional (3D-) whole body laser scanning provides a promising technique granting the opportunity to assess dozens of individual body measures at once with high accuracy and within only a few seconds of time [1]. Body scanning is utilized in medical application, e.g. for cosmetic and reconstructive surgery [2, 3], and increasingly in health research to study anthropometry of hundreds to thousands of participants in epidemiological cohort studies [1, 4] to assess their possible relevance for health risk prediction.

The capability of 3D-laser-scanning anthropometry arises from the vast number of measured body surface dimensions that allow discovery of health risk phenotypes beyond simple, one-dimensional classification schemes based on the waist-to-hip ratio (WTH) or the body mass index (BMI). However, current applications usually do not consider the whole information provided by the set of body measures and instead, use only a small part of them often to extract only body indices such as BMI or WTH [5–8]. 3D-body scans were applied in the Leipzig Research Center for Civilization Diseases (LIFE), conducting the largest population-based study with extensive phenotyping of urban individuals in Germany [9].

Previously, we proposed a novel concept of human body types based on a machine learning to extract meta-measures from the LIFE-ADULT body scanning data [10]. However, it remains unclear how body shapes change upon ageing, and how body types describe the ageing process.

Health scientists and epidemiologists increasingly use a Life Course approach to interpret anthropometrical data because body measures such as weight, height and BMI in earlier stages of life seem to affect diseases later in life, such as obesity, type 2 diabetes, hypertension or stroke [11]. Developmental trajectory-types enabled to assess the relation between body shape and the mortality risk [12]. The results indicate the health benefit of body shape management across the lifespan, but they also underline the necessity of developing elaborated measures of body shapes and their age-depending characterisation.

In this publication, we aim at studying and characterizing systematic alterations of anthropometric measures as a function of participant's age using cross-sectional data derived from 3D-laser scanning technique of the LIFE-ADULT cohort. Hereby we direct our special focus towards alterations of body shapes of participants based on their stratification into body types according to our previous classification scheme.

Results

Ageing as seen by body indices

We stratified the 8,499 participants by sex and age to estimate the alterations of 'classical' anthropometrical characteristics (body height, weight, body mass index (BMI) and waist-to-hip circumference ratio (WTH)) upon ageing (Figure 1). Body heights of both sexes start to decrease from an age of about 50 years. The lower quantile of body height in younger participants (< 50 years) approximately corresponds to the upper quantile in older ones (> 70 years). The weight of the participants alters in an opposed fashion. It increases with age up to 55-59 years, and then it declines. Combination of height and weight results in increasing BMI values up to about 60 years and virtually invariant BMI values for older people. BMI curves of both sexes are very similar, however, men show a slightly higher mean BMI than women. The age-dependency of WTH resembles that of BMI, where however men show typically markedly higher values compared to women. Among people older than 50 years, more than 50% show an 'apple-like' body shape (WTH ≥ 0.8 and 0.9 in women and men, respectively), which is found to associate with higher health risk [13].

The body indices remain, on average, virtually invariant for women and men older than 60 years which makes them unsuitable to discriminate age-dependent trends for elderly people. Overall, about 21-23% of women and men are obese while a markedly higher fraction of about 45% of men are overweight compared with 32% of women. The relative amount of obese people increases with age while that of normal weight ones decreases mainly up to an age of about 60 years. More than 25% of participants older than 60 years are obese (BMI ≥ 30). In summary, standard body indices reflect typical alterations of body dimensions upon ageing, such as decreasing body height and increasing WTH, sex-specifics and also deviations from linear changes as, e.g., observed for elderly people. Especially WTH, but also BMI, show sex-specific differences with relation to obesity. The anthropometrical information is however relatively rough and not sufficient for a detailed evaluation of changes of the body shape upon ageing.

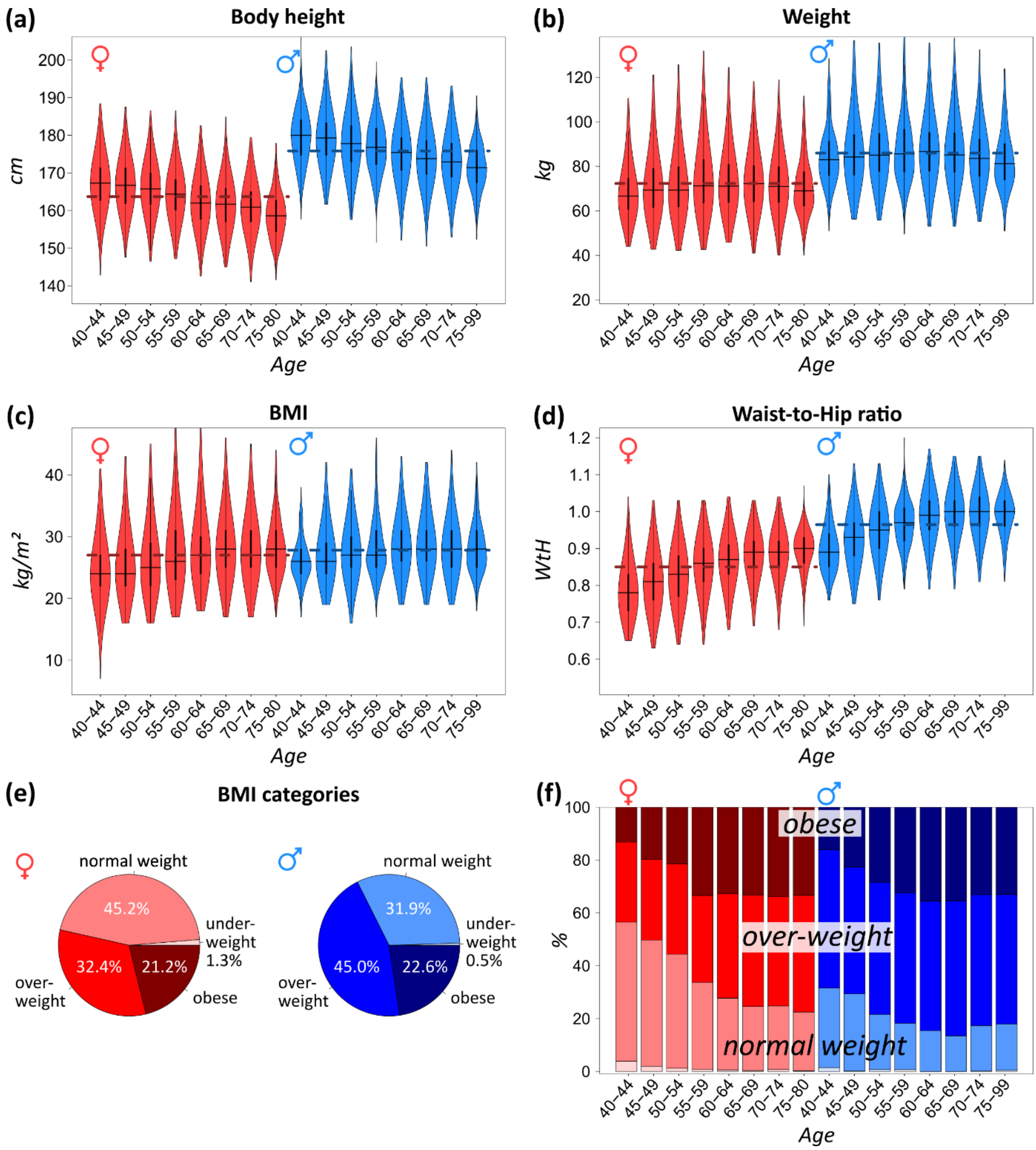


Figure 21: Classical anthropometric measures as a function of age. **(a) Body height, (b) weight, (c) BMI and (d) waist-to-hip circumference ratio are given as violin plots stratified by sex and age, respectively. Dashed horizontal lines refer to mean values for women and men, respectively. (e) The overall distribution of participants classified as underweight (BMI<18.5), normal weight (18.5≤BMI<25), over-weight (25≤BMI<30), and obese (BMI≥30) according to WHO classification [14]. (f) BMI categories stratified by age.**

Ageing body shapes

Next, we analysed age-related alterations of the body meta-measures which distribute virtually over all parts of the body (**Figure 22**a). Most of them positively correlate with age (Pearson correlation coefficients between 0.2 and 0.5, whereby correlation is stronger for women than for men in most cases, **Figure 22**b). In contrast, thigh girth and upper body lengths decrease with age on the average as indicated by negative correlation coefficients.

For visualization of the meta-measures and of their changes, we use a polar diagram termed 'bodygram', where each axis refers to one meta-measure (**Figure 22**c). The bodygrams reveal marked sex-specific differences such as larger dimensions of the upper body (meta-measures H – M) in men, and larger girth and length dimensions of the legs (meta-measures C and F) in women (**Figure 22**c, left part) meaning that the leg measures were larger in women in relation to their body height. For an age-dependent view, we generated mean bodygrams averaged over decadal age intervals (**Figure 22**c, right part), and difference bodygrams between the youngest (40-49 years) and oldest (70-80 years) strata (**Figure 22**c). Interestingly, these Δ-bodygrams are very similar for women and men indicating similar changes of the body measures upon ageing despite the distinct gender specifics of the bodygrams. In correspondence with the correlation analysis, we found that all meta-measures increase upon ageing except for meta-measure H estimating upper body lengths. These opposite trends indicate reshaping of the body towards a smaller torso in relation to body size in older individuals. The increasing meta-measures collect mainly girth measures reflecting a gain of body volume and weight as discussed above. Other meta-measures such as J and L (neck length and arm girths, respectively) markedly increase in women while C (thigh girth) increases typically in men. The latter alterations reflect redistributions of body mass from legs towards the torso, or, in other words, the shift from a pear-like towards an apple-like body shape. Overall, we documented alterations of the anthropometrical meta-measures extracted from 3D-body scanning. They reflect marked sex-specific differences of the body shapes as expected, but, at the same time, similar reshaping trends of women's and men's bodies upon ageing.

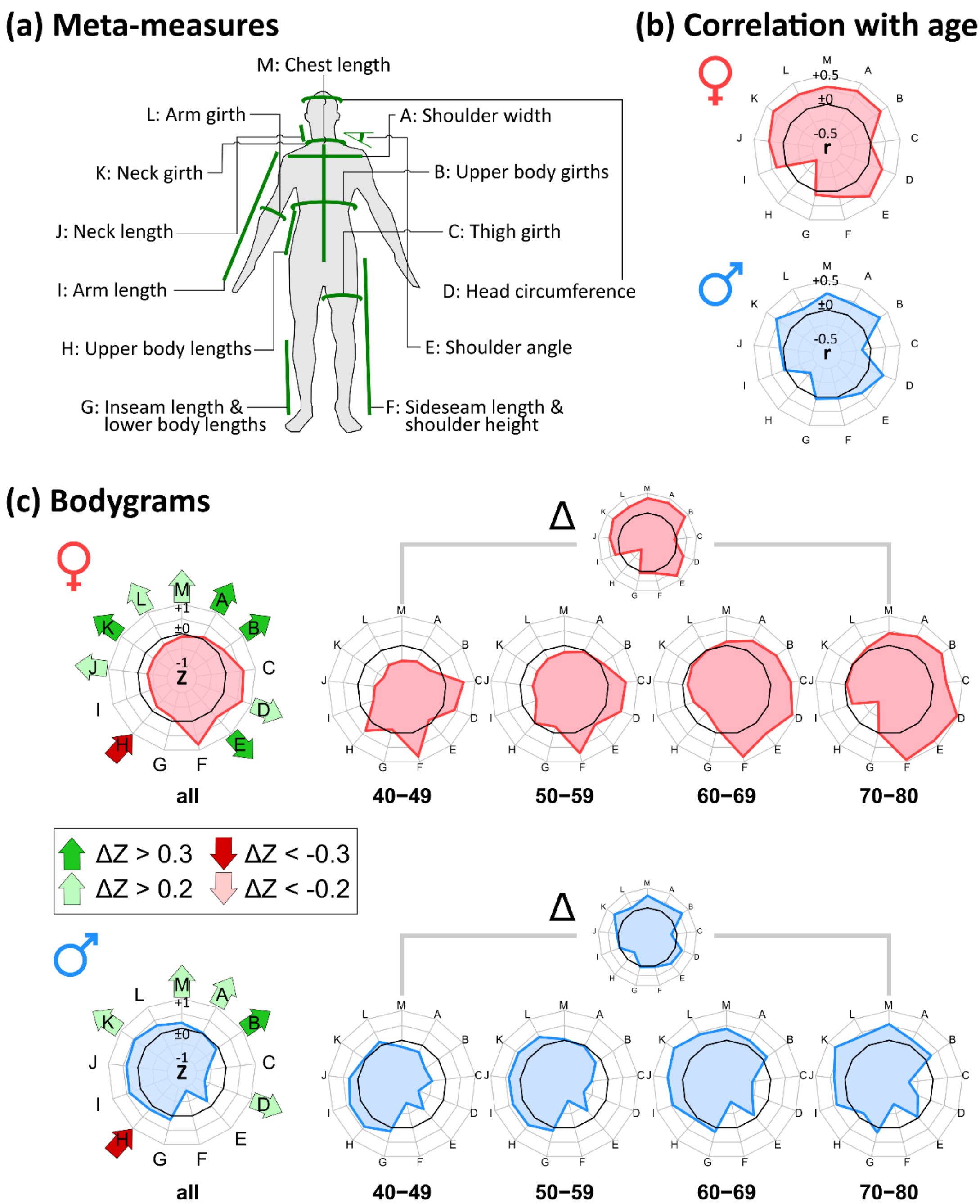


Figure 22: Alterations of body measures with age. **(a) Assignment of the 13 meta-measures defined previously. (b) Correlation of the meta-measures with age visualized as polar diagram. The black polygon refers to r=0. (c) The 'bodygram' visualizes the meta-measures in Z-units as a polar diagram. The black polygon refers to Z=0. Mean bodygrams of male and female participants averaged over all ages (left part) and after stratification into age-decades (right part) reveal gender-specific differences and age-dependent changes of the meta-measures. Difference Δ-bodygrams visualize the changes of the meta-measures between the 40-49 years and 70-80 years intervals. The green and red arrows in the left part highlight the most pronounced differences (ΔZ > ±0.2).**

Ageing body types

In the next step, we aimed to describe age-related alterations of the 15 body types identified previously to describe the heterogeneity of body shapes observed in the population of Leipzig [10] (see also Figure S1). Each of the body types collects different age-strata of participants showing however large variances and broad mutual overlaps (**Figure 23**a). We ordered the body types with increasing mean age of their members. Female body types (F-types) show a broader range of mean ages, whereas male body (M-) types are more uniform. The gender unspecific (B-) body types collect either younger (B1) or older (B2) people and were considered separately for women (B1F, B2F) and men (B1M, B2M). Variability of male body types is higher than of female ones except for F3, which collects overweight and obese women of all ages. Age-related changes of BMI are small compared to variabilities of the body types (see below and Figure S2). Two F-types (F3 and F4) and one M-type (M5) collect mainly obese individuals (BMI>30kg/m²). Interestingly, the WTH-ratios do not reflect obese characteristics of these body types compared with the other, non-obese ones. Body types F5, F6, B2M and M7 collect the highest fractions of people older than 70 years (Figure S1).

Body grams of the body types reveal type-specific changes upon ageing (**Figure 24**c and f): Part of them are characterized mainly by increasing meta-measures (e.g. B2F, F5 & M6), while others are dominated by decreasing meta-measures (F3, F6 & M3) or show virtually age-invariant meta-measures (F2, M1, M4 & M7). In general, female body types seem to underlie stronger changes than male ones. The meta-measures can be divided into growing, shrinking and virtually invariant ones: The shoulder angle (E), for example, increases with age meaning more hanging shoulders for elderly people. Also, chest (I) and arm lengths (M) are growing measures reflecting the increase of the upper body. Decrease of the dimensions of the lower part of the body is reflected by decreasing thigh girths in men (C). Overall, ageing body types are characterized by the shift of body proportions towards a larger upper part and smaller legs, which become relatively short and lean.

Some of the meta-measures reveal gender-specific alterations, such as meta-measure B (upper body girths) which increases typically in the male body types this way reflecting the shift into apple-like body shapes. Other meta-measures, e.g., arm length (I), arm girths (J), neck girth (K) and neck length (L) specifically change in female body types and partly reflect the increase of the upper body's size. Note that B2F has a WTH value resembling more that of men than that of women (**Figure 23**d). The decrease of arm girths and neck length (J and L) in F6 indicates decreasing upper body proportions. The body types F6 and M7 collect the oldest participants with mean ages of 67.8 and 66.4 years, respectively (**Figure 23**a).

Table 10 summarizes the characteristic body shape changes observed. The major characteristics of the body types are virtually age-independent. They maintain and partly amplify their most prominent characteristics in elderly people. For example, body types with tall and lean shape (B1, F1 & M2) become longer and/or leaner (longer chest & upper body). Moreover, men with a broad neck (M4 & M7) keep this property, and participants with a massive upper body (F3 & M5) additionally get leaner legs. Overall, these results indicate that, upon ageing, slim body shapes remain slim and partly tend to become even more lean and fragile, while obese body shapes remain obese. For most of the body types, we observe sex-independent changes upon ageing as described in the previous subsection. Stratification of individuals into body types provides a more detailed picture of ageing body shapes.

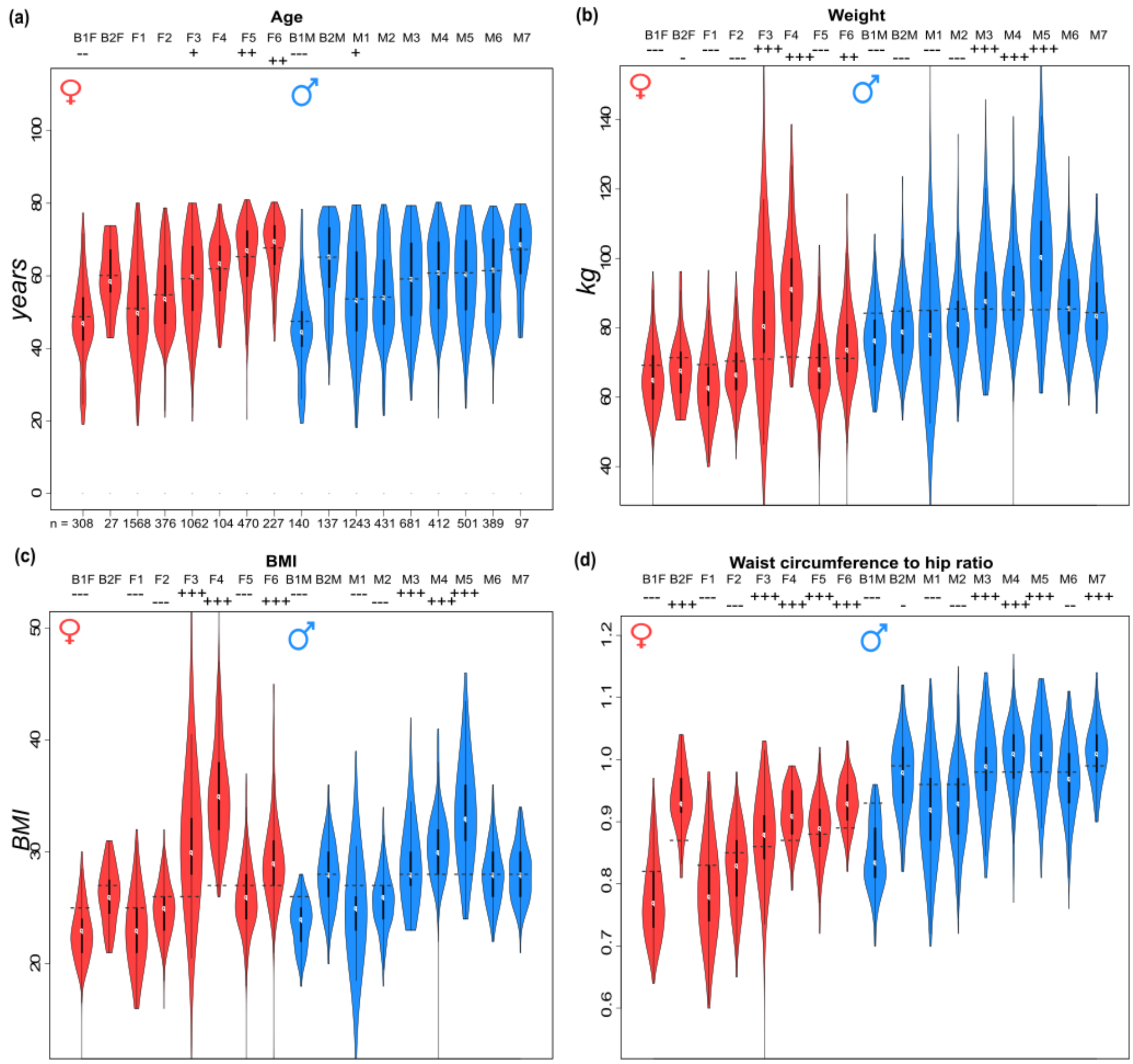


Figure 23: Anthropometric parameters of the body types: **(a) The age dependence of F-types (F1 – F6) is more pronounced than that for men (M1 – M7). (b, c) F3 and F4 are obese types among the F-types with a high variability of F3 while M5 is the most obese M-type. (d) The WTH data do not reflect these characteristics. P-values of differences between the body types groups and age-matched reference groups are indicated as signs in the head-line of each plot (p <0.1 (+/-), <0.01 (++/--) and <0.001 (+++/---).**

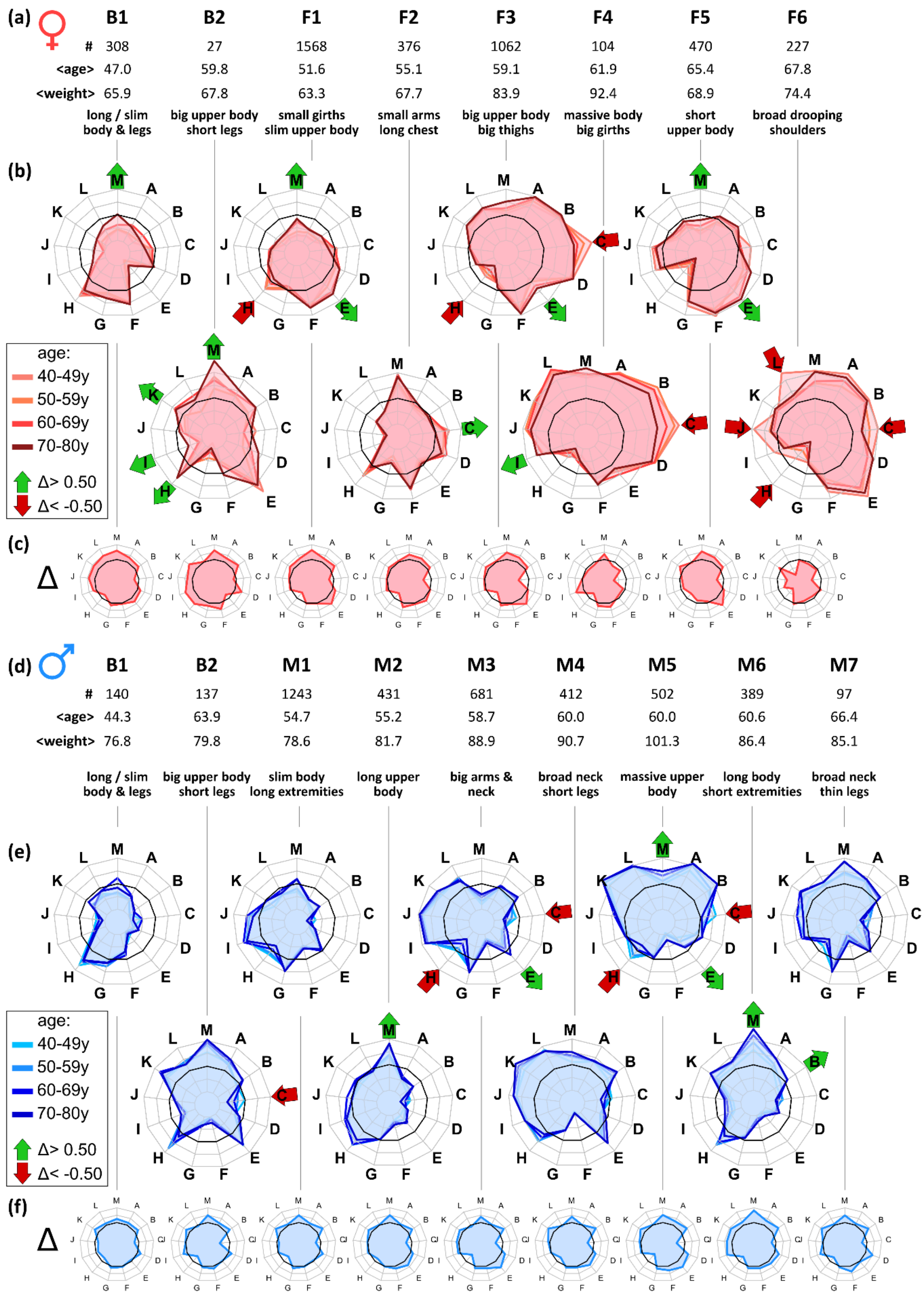


Figure 24: Ageing body types: (a) and (d) show the number of participants, their mean age and weight per body type as defined in [10]. (b) and (e) show body type-specific bodygrams averaged over 10-years intervals given as overlays (see legend). Meta-measures with marked increase or decrease ($\Delta Z > \pm 0.5$) are highlighted by arrows. (c) and (f) show difference Δ-bodygrams visualize to the changes of the meta-measures between the 40-49 and 70-80 intervals of each body type.

Table 10: List of body types and associated characteristics of body shape. **Men and women in mixed-gender body types (B1 & B2) are considered separately. Shifting proportions between younger (40-49 years) and older (70-80 years) participants of a body type are to be interpreted in relation to body height. Minor effects are given within brackets.**

Body type	General characteristics	Shifting proportions upon ageing
B1 (♀)	Long/slim body & legs	Longer chest
B2 (♀)	Big upper body; short legs	Longer upper body
F1	Small girths; slim upper body	Longer upper body & shorter lower body
F2	Small arms; long chest	Shorter & broader legs
F3	Big upper body; big thighs	Shorter & leaner legs
F4	Massive body; big girths	Leaner legs
F5	Short upper body	Longer chest
F6	Broad drooping shoulders	Shorter & leaner legs; smaller arms & neck
B1 (♂)	Long/slim body & legs	(Longer chest)
B2 (♂)	Big upper body; short legs	Leaner legs (& shorter upper body)
M1	Slim body; long extremities	(Shorter upper body)
M2	Long upper body	Longer chest
M3	Big arms & neck	Shorter & leaner legs
M4	Broad neck; short legs	(Broader neck & upper body)
M5	Massive upper body	Longer chest; shorter & leaner lower body
M6	Long body; short extremities	Longer & bigger upper body
M7	Broad neck; thin legs	(Broader neck)

The incidence of body types is a function of age

The mean age of the body types ranges from about 45 to more than 65 years (**Figure 23**a, **Figure 24**b and d), reflecting a systematic change of the age-distribution of the respective participants. The incidence of most of the body types markedly alters with age and locally deviates from the mean incidence, especially for younger and older people (Figure 25a). Age-dependent changes are more pronounced for women than for men as indicated by the steeper slope of the respective curves in **Figure 25**a. It corresponds to the stronger correlation of most of the meta-measures with age observed for women (**Figure 22**b). Net changes of the relative frequency of body types are all together roughly twice as much in women (±94%) as in men (±43%; **Figure 25**a, right part). Changes of the incidences of female body types are observed in the complete age range, while the incidence of most male body types remains virtually constant above 60 years.

The body types B1, F1 and M1 show the highest incidence for middle-aged people of about 40 to 50 years while their incidences then markedly decrease for elderly people, who enrich in F6 and M7. The incidence of F2, M2 and M3 is virtually independent of age. These body types collect participants from intermediate age ranges, which suggests compensation of in- and out-fluxes of type members upon ageing.

Taken together, we find gender-specific ageing of body shape where alterations of women are more pronounced than shape changes of men. Ageing is characterized by the redistributions of body shapes towards specific body types of elderly people showing a narrower age distribution than body types of younger people (Figure 25b).

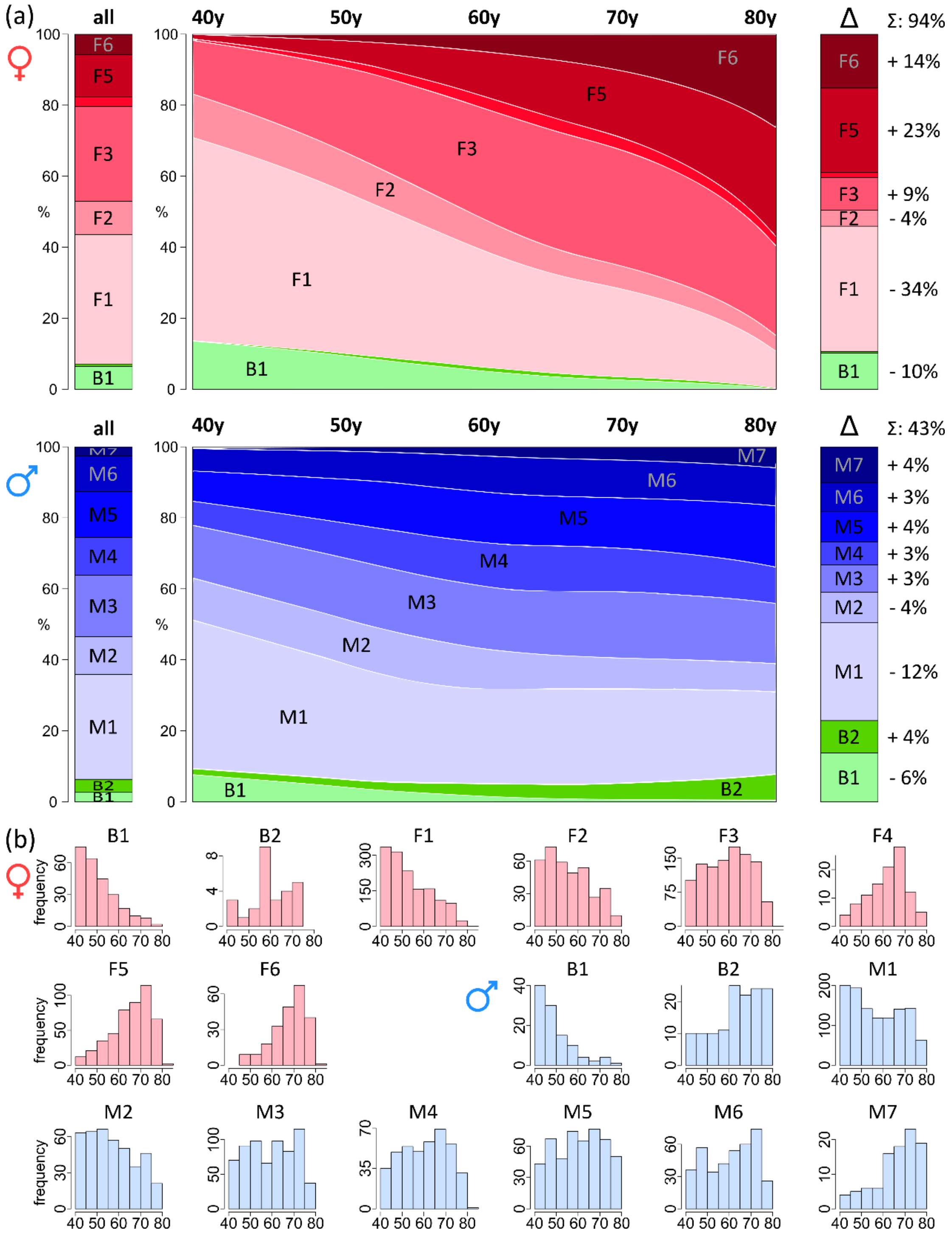


Figure 25: The distribution of body types reveals a systematic shift from young- to older-age body types. **(a) Percentage distribution of participants per body types as a function of age (middle part). The sidebars show the respective percentages of individuals in each of the body types averaged over all ages (left side) and their changes between the latest and earlies age interval (right side), respectively. (b) Frequency distribution of age of the participants collected in the individual body types.**

Transitions between the body types suggest Life Course trajectories

So far, age-dependent alterations are described by changes of the mean meta-measures (**Figure 24**) and by the changing incidences of the body types (**Figure 25**a). Both effects are linked because alterations of the meta-measures potentially change the incidences of the body types due to the re-classification of individuals between them. We applied a probabilistic approach to estimate such transitions. They are assumed to refer to pairs of individuals from two different body types with similar body shapes and they are obtained by counting all such similarity links between all pairwise combinations of body types (see heatmaps in **Figure 26**a and b).

We found such links especially between 'younger' body types (B1, M1 and M2 for men, and B1, F1 and F2 for women). Their number strongly decreases with increasing age (supplementary text). Body types of the intermediate age-range (M3 – M5, and F3) form 'transition' types linking 'younger' with the 'older' body types. The links typically refer to a relative shortening and broadening of the upper body (decreasing meta-measure H, increasing meta-measures B, K and L; see supplementary text). For example, the intermediate position of F3 suggests transitions from F1 and F2 towards F3 and from F3 towards F5 and F6 (see **Figure 26**c). For men, links reflect a less pronounced age-structure (**Figure 26**d) in correspondence with the weaker age-dependent changes of male body types (**Figure 4**a). Interestingly, F4 (women with massive bodies and thick girts) forms a relatively isolated body type virtually without similarity links to other body types. Younger women of the androgynous body type B1 link to F1, and younger men of B1 link to M1, whereby all of them collect slim bodies. The second androgynous body type B2 (big upper body) links to M4 – M6 which all show larger upper body dimensions. In summary, similarity relations between individuals of different body types enabled us to identify possible transitions between the body types upon ageing. They can be summarized into two major Life Course trajectories for women linking the younger and older body types F1 and F5, respectively, either by direct transitions or via the obese type F3, both affecting predominantly the dimensions of the upper body. For men, possible trajectories are more diverse, involve more inter-linked body types and affect different parts of the body. Also for men one this pattern of links reflects two major Life Courses, one via the obese type M5 and the other via the tall types M2 and M6.

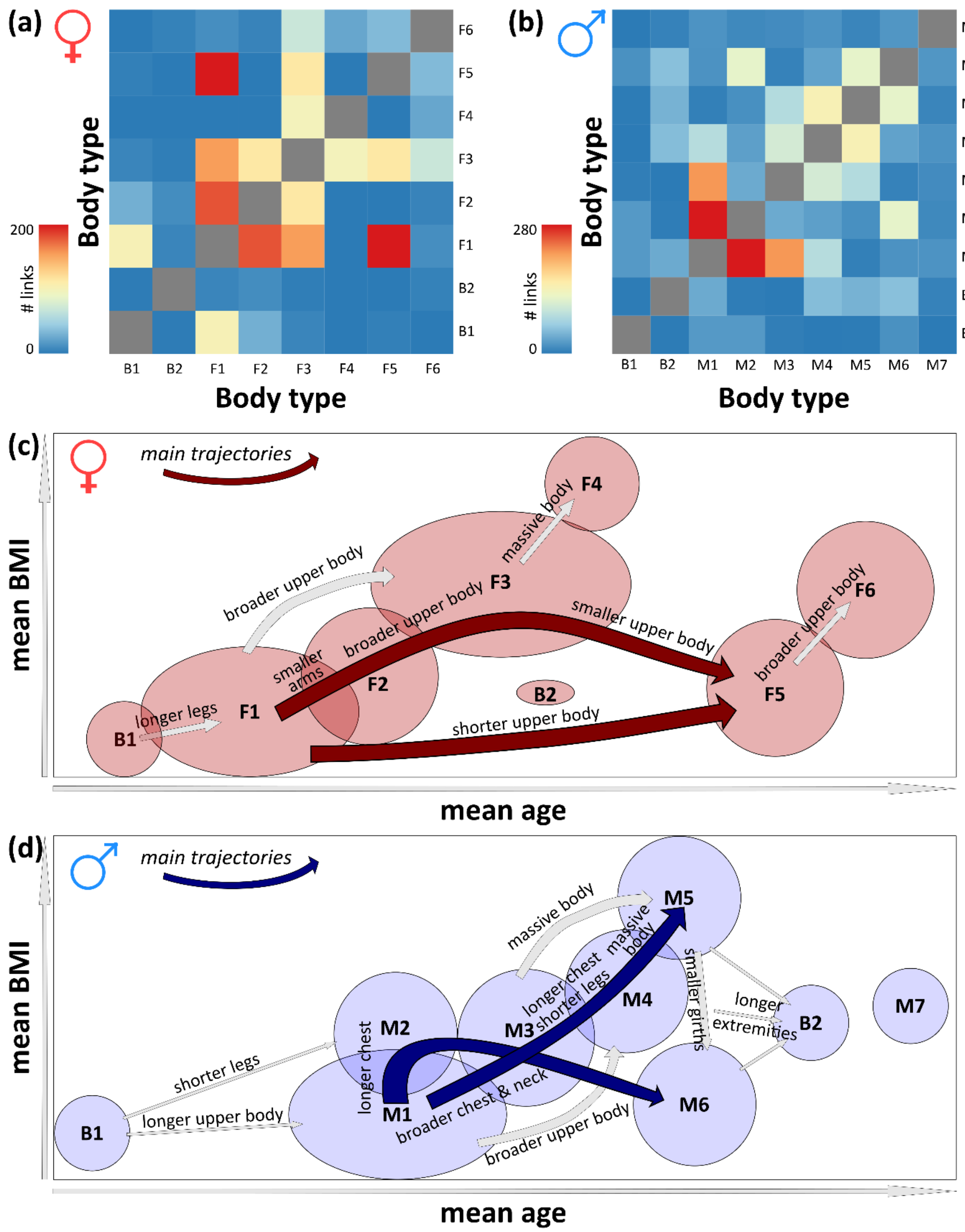


Figure 26: Similarity links suggest an age course of body types: **Frequencies of similarity links between female (panel a) and male (panel b) body types are shown as heatmaps. These link frequencies were used to construct a schematic overview of transitions between the body types in an age-versus-BMI coordinate system. It suggests a partly linear sequence of female body types (c), and a more compact structure for male ones with more mutual transitions between the different body types (d). Intersecting areas and arrow widths approximately scale with the number of corresponding links (see also Figures S6 & S7 for more details).**

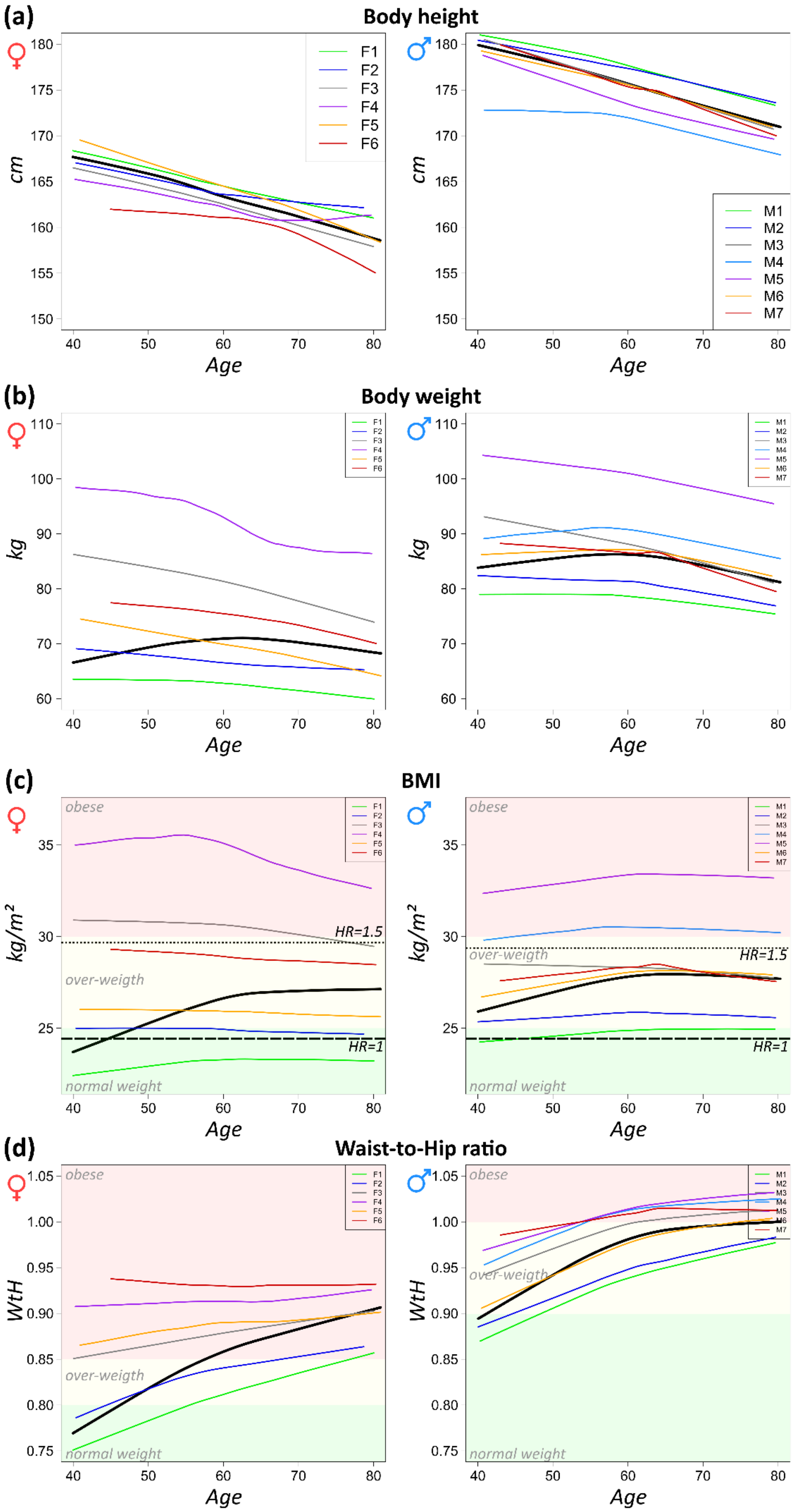
Body types diversify the ageing curves of anthropometric indices

We found that most body types develop specifically upon ageing. For their better characterization, we decomposed the age-dependencies of the 'classical body indices' discussed in subsection 3.1 separately for each body type (**Figure 27**). The body type-specific curves of body height roughly follow the course of the mean body height averaged over all participants (thick curve) with a slight scatter between them reflecting different body height levels. In contrast, the body weight and especially BMI curves of the individual body types show much stronger scattering (**Figure 27**b, c).

Importantly, the BMI of the body types remains virtually constant while the overall mean BMI increases until the age of 60-65 years. In other words, body typing roughly stratifies the population into virtually age-independent BMI-levels, especially for women in the order F1< F2< F5< F6< F3< F4 and, to a less degree for men M1< M2< (M3≈ M6≈ M7) <M4< M5. M3, M6 and M7 are characterized by similar BMI- (and body-height-), but different WTH-levels. The relative small scatter between the body-height curves of the individual body types indicates that body height is only a relatively weak determinant of body typing, while the much larger spread of the weight-curves reflects its larger impact on BMI.

The WTH index is steadily increasing with age in most body types reflecting a general apple-to-pear like shift of body shapes, where the slope is largest for female body types with smallest WTH (F1, F2). WTH seems less suited as an age-independent marker-index of body shape. The slope of the different WTH-curves decreases with increasing WTH level, especially for women, leading to convergence of WTH-indices and thus of stable pear-like body shape for elderly people. F6, accumulating elderly women, shows virtually constant WTH over age, and M5, accumulating obese men, is even slightly decreasing for participants older than 60 years.

The mean BMI-levels of F2 and M1 roughly correspond to a BMI value of about 24 kg/m² which associates with minimum all-cause mortality [15]. The more obese types F4, M4 and, especially F3 and M5 seem to associate with an increased risk based on previous data linking mortality risk and BMI [15]. Overall, stratification of body shapes into distinct body types levels out age-related alterations of body indices and enables the study of health-related associations in terms of defined anthropometric groups.



(a)
Body height
F1
F2
F3
F4
F5
F6
M1
M2
M3
M4
M5
M6
M7
cm
Age
(b)
Body weight
kg
(c)
BMI
obese
over-weigth
normal weight
HR=1.5
HR=1
kg/m²
(d)
Waist-to-Hip ratio
WtH

Figure 27: Body height, weight, BMI, and WTH of body types as a function of age. **Curves were smoothed for each body type. Thick black lines indicate the mean parameter development averaged over all female (left panels) and male participants (right panels), respectively. Gender unspecific body types B1 and B2 were discarded from this analysis due to too low sample sizes. The background colours in (c) and (d) indicate different weight categories as indicated. The horizontal dashed line refers to minimum BMI-associated all-cause mortality (BMI=24 kg/m^2) and the dotted lines to hazard ratios of 1.5 taken from [15].**

Association between body types, physical activity and selected health and lifestyle factors

Next, we studied the physical activity of the participants of the LIFE study as a function of age and its association to the body types. The numbers of steps per day and the metabolic equivalent (MET) as measures of physical activity systematically decrease with age similarly for women and men (**Figure 29**a). Among the body types we identified more (F1, M1) and less (F3, F4, M5) active ones using age-matched reference groups for comparison (p-value<0.001, Wilcoxon rank-sum test, **Figure 29**b). The mean MET-value of the body types decreases as a function of age except for the most obese type F4 (**Figure 29**c). The MET-levels anti-correlate with BMI and weight values (compare with **Figure 27**, r=-0.87). The plots of the mean BMI and MET values per body type as a function of their mean age can be roughly described by lines of opposite slopes (**Figure 29**d), but obese body types (F3, F4, M5 and to a less degree, M3, M4) deviate from these lines towards low MET, while B2F has a slightly elevated MET value. Note that MET is normalized per kg of body weight. Consequently, the treated energy grows not in parallel to body weight of the participants. Low MET-values were found particularly for F3, F4, and also M5, which were risk groups in terms of high BMI (see above).

We use the history of myocardial infarction (i.e. the prevalence of myocardial infarction in the previous life of participants, PMI) as one proxy to estimate the health risk of the body types. PMI of male body types markedly exceeds PMI in nearly all female body types except for B2F (**Figure 29**a). PMI steeply increases with the mean age for men's types but to a markedly less degree for women (**Figure 29**b). We find slightly increased PMI for obese risk-types of men (M5), while PMI is maximal for M7, presumably because of the increased mean age of this type (66.7 years). Age is obviously a relevant risk factor for elderly men compared to BMI and physical activity. Among women, the androgynous type B2F shows strikingly high PMI. Notably, PMI is virtually independent of BMI and MET for women of all body types except for B2F, while it increases/decreases with BMI/MET for men's body types. Surprisingly, no case of previous myocardial infarction is among F4 collecting obese and elderly women (p=0.11). Also F3, another obese body type, associates with a relatively small PMI-level. On the other hand, F3 and F4 collect, on the average, younger women than F5 and F6, suggesting that age constitutes the more relevant risk factor of PMI for women in contrast to men, who are under increased risk with increasing BMI for most body types.

The high PMI of the female B2F group is noteworthy, and it even exceeds the PMI-levels of men's body types (except M7). Androgynous women are obviously under elevated risk for myocardial infarction. To better understand this anomaly, we included alcohol consumption and smoking status as lifestyle factors, and also medication data available for the LIFE participants into our analysis. Particularly, medication of the group 'C: cardiovascular system' according to Anatomical Therapeutic Chemical (ATC) Classification shows similar patterns as PMI, e.g. higher percentage of medication in B2F and M7 (**Figure 29**c). Obese and elderly women of body types F4 – F6 take more medication than men of all BMI categories except for oldest (M7) men. B2F women, on the other hand, take virtually no drugs of the medication categories 'G: genito-urinary system and sex hormones' and 'H: Systemic hormonal preparations, excluding sex hormones and insulins', which considerably deviates from women of the other female body types. Women consume, on average, less alcohol than men, and the consumption decreases for body types of elderly women but without marked specifics for B2F individuals (**Figure 29**d). In contrast, B2F women show highest smoking level among women, which is comparable with that of men: 56% in B2F compared with 40% for all women and 59% for all men.

In summary, the physical activity of participants measured in units of metabolic equivalent anti-correlates with BMI and decays with age. Prevalence of myocardial infarction increases with age and/or BMI among men, but it is low among women except those of the androgynous body type B2F which, in turn, associates with high medication of group C drugs and relative extensive smoking.

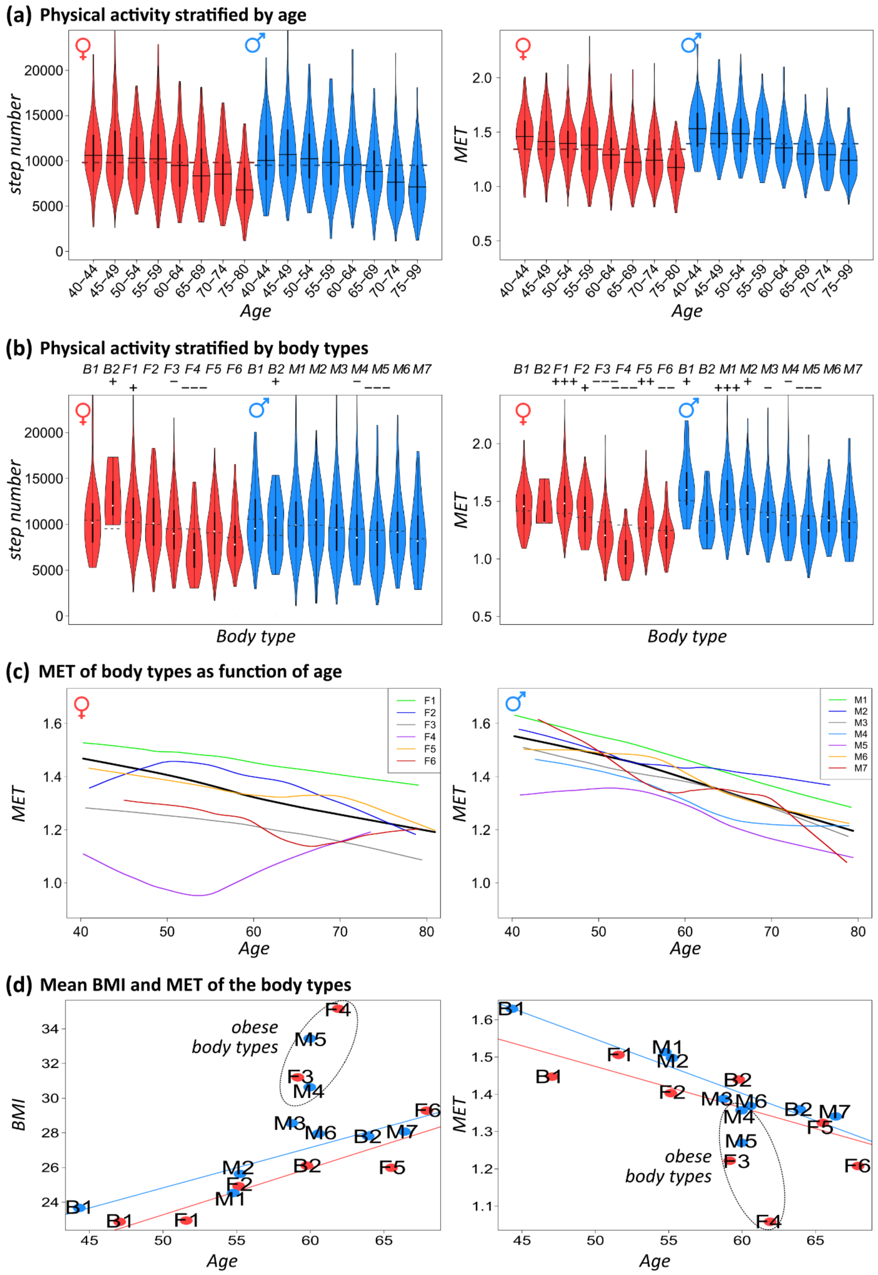


Figure 28: Physical activity of body types: **a) Physical activity as measured in units of the number of steps per day and MET decreases with age. b) Body types divide into more and less active ones, where the former category collects younger and less obese individuals. Dashed lines indicate median values of the reference age groups, "+" and "-" symbols in the head-line indicate significant differences between the body types and their reference groups with p-values of <0.1 (+/-), <0.01 (++/--) and <0.001 (+++/---), respectively. c) MET of the body types as a function of age resemble the respective BMI-curves in Figure 27 and reflects that high BMI associates with low physical activity. d) The plot of body types' mean BMI as a function of their mean age can be roughly described by lines of similar positive slopes for women and men (≈ 0.25 kg/m² per year) if one excludes the obese types F3, F4, M5 and M4. MET provides negative slopes with larger variability of the values of the F-types and F4 as outlier showing lowest MET value.**

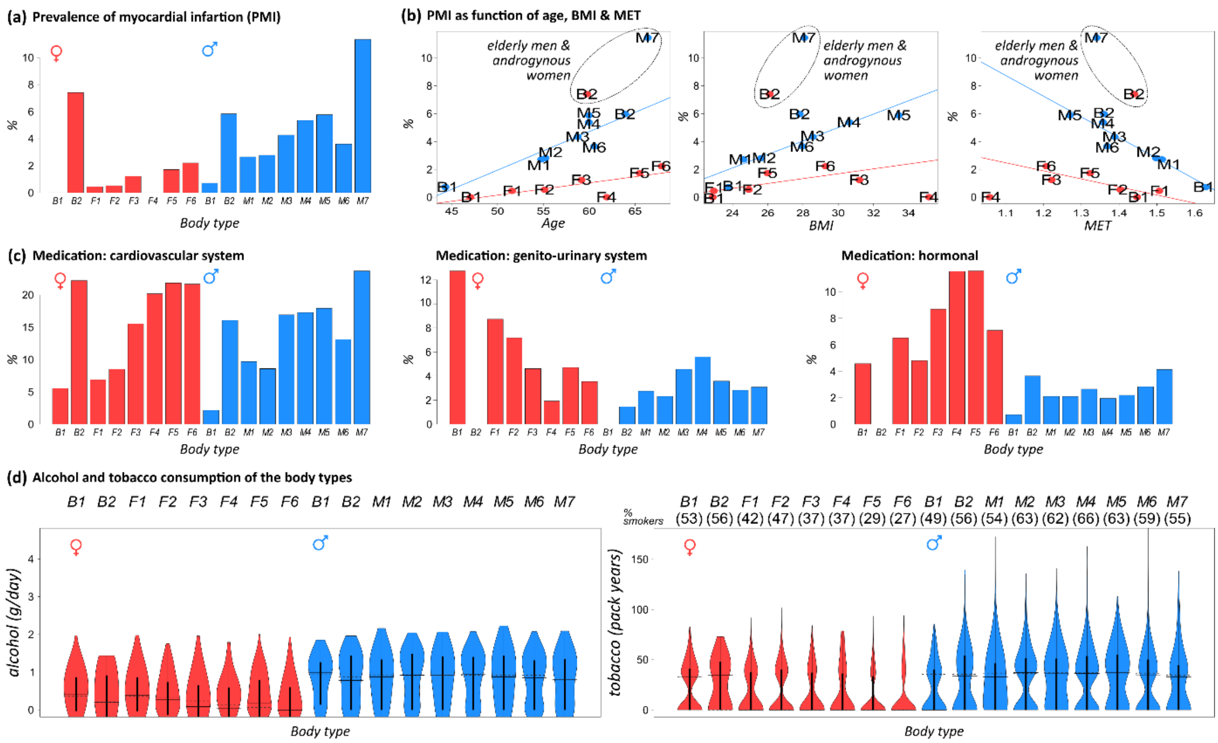


Figure 29: Myocardial infarction prevalence, lifestyle factors and medication in body types: a) Prevalence of myocardial infarction is much smaller for female (1.1%) compared with male (4.1%)

participants of the LIFE study where however women of the B2F type have a strikingly high PMI value (7.4%). (b) Plots of PMI as a function of age, BMI and MET consequently reveal much steeper slopes for M-types than for F-types. Women of the androgynous body type B2F are disproportionately affected by myocardial infarction. c) Medication frequency of the individuals of the body types (within 7 days before their examination in LIFE) with drugs of the ATC-groups C (cardiovascular system), G (genito-urinary system and sex hormones) and H (systemic hormonal preparations, excluding sex hormones and insulins), which all show anomalies for B2F. (d) Violin plots of the lifestyle factors alcohol consumption and smoking stratified by the body types. Alcohol consumption is higher for men than for women, and it slightly decreases with the mean age of the body types. Smoking among B-type women is more intense than among the other F-types and resembles that of men. Note that the violin plots reflect a bi-modal distribution for most of body types referring to non-smokers and smokers, respectively ('smokers' here subsumes current and former smoking; see percentage of smokers in the body type as indicated in the header).

Discussion

Body typing resolves the diversity of ageing body shapes

We studied the effect of ageing on the body shape of about 8,500 adult people of Middle European ethnicity randomly selected from the population of Leipzig, Germany. As the major trend of 'classical' anthropometry upon ageing, we observed a decrease of body height, a moderate increase of BMI towards obese and overweight characteristics and the increase of waist-to-hip (WTH) ratio reflecting changes, popularly described as apple-to-pear like body shape transformations. Human body shapes are however more diverse requiring a more detailed description as a methodical basis to study possible associations with health and lifestyle factors.

Here we for the first time applied our body typing approach to resolve the multidimensionality of anthropometrical data extracted from 3D-body scanner measurements. Our method reduces the about 150 derived body measures into 13 relevant anthropometric dimensions called 'meta-measures'. These meta-measures reflect marked sex-specific differences resulting in the clear division into F- (female) and M- (male) body types. They were used to diversify human body shapes into fifteen body types, six of them for female participants, seven for male ones, and two mixed-gender types (see [10] for details). Ageing results in virtually sex-independent reshaping of female and male bodies, which is characterized by the shortening and widening of upper body dimensions and an expansion of the leg girths of women and arm girths of men. With increasing age, slim body shapes remain slim whereas obese body shapes tend to remain obese. We find marked sex-differences of the distribution of body types upon ageing: The populations of F-types change twice as large, in terms of cumulative percentages, compared with those of men. The age dependencies of the mean anthropometric indices (BMI, WTH) do not reveal such differences. Making use of similarities between the body measures of different body types, we deduced possible Life Course trajectories based on the frequencies of possible transitions between the types. For women and men, we identified two main ageing paths referring to more obese and to normal-weight individuals, respectively. For men, trajectories seem more complex particularly because of a network-like structure of links between the body types. Overall, female body shapes are more diverse and change more strongly than male ones. Anthropometric changes in terms of body types and indices begin to level off in the age range between 55 and 60 years as a characteristic of elderly people.

Body typing resolves BMI strata and impacts health risks

Several anthropometric measures such as BMI, WTH, but also waist-to-height ratio [16] and ‘A body shape index’ (ABSI) [17] have been developed to judge the health status in terms of obesity, mortality, and biological age [18] using simple, ‘one-dimensional’ measures. For example, discussion has developed around the so-called ‘obesity-mortality paradox’ stating that mortality shows a U-shaped dependence on BMI with a minimum at about 25 kg/m² [15]. Other studies showed that confounding factors and/or other anthropometric measures remove the protecting effect of body fat on risk [19]. Beyond this, there is growing evidence that a certain level of, e.g., BMI (or other anthropometric indices) can associate with different disease risks due to differences between ‘metabolic-healthy’ and ‘-unhealty’ physiological states [20], and also because a series of confounders, e.g., age, sex, genetic factors, cardio-metabolic fitness and pre-existing diseases. Our body typing offers a novel multidimensional metrics of anthropometry, which aims to fully exploit the data provided by 3D-laser scanning. Importantly, our body types divide men and women into strata of virtually age-independent mean BMI levels ranging from underweight to obese characteristics. On the other hand, some body types represent different body shapes for similar BMI levels, e.g. the slightly overweight types M3, M6 and M7 (see **Table 10**).

We here used participant-matched data on the prevalence for myocardial infarction and physical activity as example-features to estimate the possible impact of body types on their health and ageing behaviour. Overall, physical activity (MET) is inversely related to BMI and decreases with age. Obese body types reveal markedly small MET-values reflecting low activity levels of these individuals. Paradoxically, these obese and 'inactive' body types are virtually inconspicuous regarding myocardial infarctions in the disease history of the respective men and, especially women. On the other hand, elderly men (M7) and women of B2F had higher prevalences of myocardial infarction (11% and 7%, respectively) compared with the other F- and M-body types with possible impact for risk prediction.

Conclusion

Body typing by utilizing 3D-body scanning data offers novel opportunities for studying the diversity of human phenotypes. Stratification of ageing human body shapes into Life Courses is one step towards personalized anthropometry with the perspective to predict lifetime risks. Verification and further development of this novel approach should include longitudinal follow up programs, wider phenotype association profiles to identify multidimensional anthropometrical risk profiles for clinics and, last but not least, improved bioinformatics for dimension reduction and focussed feature selection of this novel data type.

Data and Methods

The LIFE study and ethics approval

Our analysis included data collected in the frame of the LIFE-Adult study between 2011 and 2014 with a targeted sample size of 10,000 participants [9]. We utilized body scanner data of 8,499 participants and physical activity measurements of 2,429 participants. The study was approved by the responsible institutional ethics board of the Medical Faculty of the University of Leipzig.

3D-body scanning and anthropometric data

3D-body surface scanning was performed by a 'Vitus Smart XXL' 3D-laser scanner (Avalution GmbH, Kaiserslautern, Germany) which provides an image of the body surface of each participant. In total, 155 body measures were extracted from each of these images using AnthroScan 2.9.9 software in agreement with ISO 20685, the international anthropometric database standard for 3D scanning methodologies.

We considered 134 body measures of 8,499 participants including length and girth measures, weight, and the indices 'body mass index' (BMI [21]), 'waist to hip circumference ratio' (WtH [13]), 'waist circumference to height ratio' (WHtR [16]) and 'a body shape index' (ABSI [17]). The body measures of each participant were divided by the body height to get height-normalized values. Each measure was then Z-normalized, which makes the different measures comparable. Details about data preprocessing are given in [10].

Meta-measures and body types

We analyzed 3D-body scanning data based on self-organizing map (SOM) machine learning to stratify the LIFE-ADULT data into body types [10]. In brief, machine learning aggregates the body measures provided by the scanner software into a set of 13 meta-measures instead of 150 features measured by the scanner. Each meta-measure represents a cluster of correlated single body measures. They define the relevant dimension of the body shape (see **Table 11** and **Figure 22**a for illustration). Approximately half of the meta-measures collects length measures (n=7), while the other half mostly refers to girth measures (n=5) of different parts of the body.

The meta-measures were then used to cluster the participants of the study into 15 body types (see **Figure 24**a and c for illustration): Two of the body types (B1 and B2) lack gender specifics because they include both male and female participants. Six body types (F1-F6) collect almost exclusively women (F1-F6), while seven body types (M1-M7) are male-specific. The body types differ in the mean age, body height, weight and BMI characteristics of the participants [10]. We defined age-matched and sex-specific reference groups for each of the body types collecting all participants in an age window of ten years independent of their body type. Body types' features, e.g. BMI and activity parameters, were then compared with those of the respective reference group and tested for significance using Wilcoxon rank-sum test.

Table 11: List of meta-measures and most prominent associated body measures. **Meta-measures are labelled with capital letters.**

Meta-measure		**Associated body measures**
A	Shoulder width	Shoulder width, width of armpits, cross shoulder length
B	Upper body girths	Chest girth, waist girth, hip girth, belly circumference, BMI, WHtR
C	Thigh girth	Thigh girth (left & right)
D	Head circumference	Head circumference, crotch length
E	Shoulder angle	Shoulder angle (left & right)
F	Sideseam length	Sideseam length (left & right), ankle height (sideseam left & right), head height
G	Inseam length	Inseam length (left & right), ankle height (inseam left & right), crotch height
H	Upper body lengths	Distance neck to hip, distance neck to knee, distance waist to knee
I	Arm length	Arm length (left & right), up arm length (left & right)
J	Neck length	Neck length

K	Neck girth	Neck girth (at base & middle)
L	Arm girth	Arm girth (forearm, up arm, elbow; each left & right), ankle girths (left & right)
M	Torso length	Neck to waist distances (left, right, central)

Similarity links between body types

For comparison of the body types, we estimated their mutual similarities by calculating the Euclidian distance of the meta-measures between all pairwise combinations of participants. The number of most similar pairs then defines links between the corresponding body types. In supplementary material, we stratify body type links by age, and associate differential meta-measures to them (Figures S6 & S7). Changes of the body type with age are assumed to occur along these links.

Physical activity data and metabolic equivalent (MET) estimation

Physical activity status of a subcohort of 2,429 participants (1,319 men and 1,100 women) was estimated in units of metabolic equivalent (MET) using the SenseWear Pro Armband (SWA, Bodymedia, Inc., Pittsburgh), a multi-sensor tool with 2-axis-accelerometer, heat flux sensor, galvanic skin response sensor, skin temperature sensor, a near body ambient temperature sensor, and heart rate detection using a chest strap [22]. It was used by participants on 8 days or more, including at least 4 weekdays and one weekend day [23]. We only consider days with sufficient wearing time of at least 18 hours on weekdays, or at least 20 hours on weekend days [24]. Under these conditions, the SWA delivers valid and reliable data as proven by several validation studies [23, 25–27]. The SWA software estimates physical activity in units of metabolic equivalent (MET), where a MET value of unity refers to the amount of oxygen consumed while sitting at total rest. It is set equal to 3.5 ml O2 per kg body weight and minute [28]. In addition to MET, we also used the ‘number of steps per day’ of the participants counted by SWA during the measurement as a rough direct estimate of physical activity. The SWA has limitations leading to lower accuracy e.g. while cycling, and it cannot be worn while swimming [24].

History of myocardial infarction, medication and lifestyle factors

History of myocardial infarction of LIFE participants was assessed in questionnaires and refers to at least one previous infarction during their lifetime. It amounts to 4.3% of men and 1.2% of women in the LIFE sample. These percentages are lower than the mean lifetime prevalence for myocardial infarction of the German population (age range: 40-79 years) of 7% and 2.5%, respectively [29]. Further, we make use of selected lifestyle characteristics of the participants such as cigarette and alcohol consumption, and medication status collected via questionnaires.

Data availability

Participant data presented in this publication are not publicly available due to limitations of informed consent. However, these data are available from the corresponding author on reasonable request. The anthropometric data are available from 'The Leipzig Health Atlas' repository under accession number 7XUCQW5V05-3 (https://health-atlas.de/lha/7XUCQW5V05-3).

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Author contributions

ML and KW conceived and designed the experiments. HLW, NW and AF analyzed the data. AF, HLW and HB wrote the paper. All co-authors contributed to manuscript writing, and read and approved the manuscript.

Competing interests

The Authors declare no competing financial or non-financial interests.

Additional material

Additional file 1: Supplementary text.

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Erklärung über die eigenständige Abfassung der Arbeit

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und ohne unzulässige Hilfe oder Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Ich versichere, dass Dritte von mir weder unmittelbar noch mittelbar eine Vergütung oder geldwerte Leistungen für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen, und dass die vorgelegte Arbeit weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde zum Zweck einer Promotion oder eines anderen Prüfungsverfahrens vorgelegt wurde. Alles aus anderen Quellen und von anderen Personen übernommene Material, das in der Arbeit verwendet wurde oder auf das direkt Bezug genommen wird, wurde als solches kenntlich gemacht. Insbesondere wurden alle Personen genannt, die direkt an der Entstehung der vorliegenden Arbeit beteiligt waren. Die aktuellen gesetzlichen Vorgaben in Bezug auf die Zulassung der klinischen Studien, die Bestimmungen des Tierschutzgesetzes, die Bestimmungen des Gentechnikgesetzes und die allgemeinen Datenschutzbestimmungen wurden eingehalten. Ich versichere, dass ich die Regelungen der Satzung der Universität Leipzig zur Sicherung guter wissenschaftlicher Praxis kenne und eingehalten habe.

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Datum Unterschrift

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Lebenslauf

A L E X A N D E R   F R E N Z E L

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20.07.2015 bis 21.08.2015	Famulatur Chirurgie, Kantonsspital Glarus (CH), Chefarzt Dr. med. Andre Rotzer
21.11.2016 bis 12.03.2017	1. Tertial des Praktischen Jahres, Wahlfach Orthopädie, Caritas Krankenhaus Bad Mergentheim, Chefarzt Prof. Dr. med. Christoph Eingartner

13.03.2017 bis 02.07.2017	2.Tertial des Praktischen Jahres, Chirurgie, Kantonsspital Glarus (CH), Chefärztin PD Dr. med. Eliane Angst
03.07.2017 bis 22.102017	3. Tertial des Praktischen Jahres, Innere Medizin, Universitätskliniku Leipzig, Abteilung für Gastroenterologie
und	Rheumatologie, Chefarzt Prof. Dr. med. Joachim Mössner

BERUFLICHER WERDEGANG:

Approbation seit 22.01.2018, erteilt vom Freistaat Sachsen
seit dem 01.04.2018 Assistenzarzt in der Weiterbildung zum Facharzt für Orthopädie und Unfallchirurgie in der Abteilung für Operative Orthopädie der Sana Kliniken Sommerfeld, Chefarzt Prof. Dr. med. Andreas M. Halder

WEITERBILDUNG:

Sonographie:	Vorlesung mit praktischen Übungen „Internistischer Ultraschall“, WS 15/16, Prof Dr. med. Volker
Keim	
EKG:	„Praxisbezogener systematischer EKG-Kurs“, WS 2014/2015, Prof. Dr.med. Dietrich Pfeifer und Dr. med. Martin Neef
Tropenmedizin	Vorlesungsreihe mit praktischen Übungen SS 2014, PD Dr. med Christoph Lübbert
Manuelle Medizin	3 von 6 Kursen für die Zusatzbezeichnung Manuelle Medizin
Fachkunde im Strahlenschutz	seit 2019 für Skeletttröntgen (Wirbelsäule und Extremitäten)
Berliner Arthroskopiekurs	04/2019
MRT Kurs	07/2019 Thema: Wirbelsäule

DISSERTATION

Seit 21.01.2016	Review about 3D-body scanning in the LIFE sample and their characteristics in anthropometric, actometric and medical context Interdiziplinärem Zentrum für Bioinformatik (IZBI), Uni Leipzig Betreuer: Prof. Dr. med. Markus Löffler

SPRACHKENNTNISSE

Englisch (Medizinische Fachsprache, UNIcert Stufe III)
Spanisch (schriftlich und mündlich)