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Measurement of cardiorespiratory fitness in the German Health Interview and Examination Survey for Adults (DEGS1)

Introduction

Physical activity is an important factor in the prevention and treatment of chronic diseases, to increase wellbeing, and to reduce premature mortality [1, 2]. Physical fitness is closely related to physical activity and can be modified by regular physical activity [3]. Physical fitness comprises health-related components such as cardiorespiratory fitness (endurance), muscular endurance, muscular strength, body composition and flexibility [4]. Studies report that the dose–response relationship between cardiorespiratory (aerobic) fitness and health seems to be even stronger than that between physical activity and health [3, 5]. The Aerobics Centre Longitudinal Study found that the fittest men and women in the top quintile had a 43 and 53% lower relative risk of overall mortality than the least fit men and women in the bottom quintile, and a 47 and 70% lower risk of cardiovascular mortality [6, 7]. Cardiorespiratory fitness can be improved by moderate- to vigorous-intensity aerobic physical activity [8], which is for the first time explicitly recommended in the World Health Organization's updated guidelines on physical activity [9]. It is therefore the task of preventive medicine and health promotion to improve the level of cardiorespiratory fitness in the population by stimulating aerobic physical activity. In order to evaluate the success of health-promotion interventions, there is a need for research to monitor trends in cardiorespi-

ratory fitness on a population level. The objective measurement of cardiorespiratory fitness has advantages regarding the validity and reliability of results compared to subjective assessment strategies via questionnaires [10]. In the first wave of the German Health Interview and Examination Survey for Adults (DEGS1), a submaximal cycle ergometer test was used to obtain an objective evaluation of cardiorespiratory fitness in adults aged 18–64 [11].

The objective of this paper is to describe the assessment strategy, the distribution of participants by test-qualification status as well as to evaluate the generalisability of the results.

Methods

Study design

The German Health Interview and Examination Survey for Adults ("Studie zur Gesundheit Erwachsener in Deutschland", DEGS) is part of the health monitoring system at the Robert Koch Institute (RKI). Its concept and design are described in detail elsewhere [12, 13, 14, 15, 16]. DEGS1 was conducted between 2008 and 2011, and comprised interviews, examinations and tests [17, 18]. The target population comprises the residents of Germany aged 18–79 years. DEGS1 has a mixed design which permits both cross-sectional and longitudinal analysis. For this purpose, a random sample from local population registries was drawn to

complete participants of the German National Health Interview and Examination Survey 1998 (GNHIES98). A total of 8,152 persons participated, including 4,193 first-time participants (response rate 42%) and 3,959 revisiting participants of GNHIES98 (response rate 62%). In all 7,238 persons attended one of the 180 examination centres, and 914 were interviewed only. The net sample (n=7,988) permits representative cross-sectional analyses and time trend analyses for the age range 18–79 years in comparison with GNHIES98 (n=7,124) [12]. The data of the revisiting participants can be used for longitudinal analyses.

The cross-sectional and trend analyses are conducted with a weighting factor which corrects deviations in the sample from the population structure (as at 31 Dec 2010) with regard age, sex, region, nationality, type of municipality and education [13]. A separate weighting factor was used for the examination part. Calculation of the weighting factor also considered re-participation probability of GNHIES98 participants. For the purpose of conducting trend analyses, the data from the GNHIES98 were age-adjusted to the population level as of 31 Dec 2010. A non-responder analyses and a comparison of selected indicators with data from census statistics indicate a high level of representativity of the net sample for the residential population aged 18–79 years of Germany [13].

All participants were informed about the study objectives, and signed a writ-

		No contraindication according to physician
		↓
1. Has your doctor ever said that you have a heart condition and recommended physical activity only under medical supervision?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
2. In the past month, have you had pain in your chest when you were physically inactive or active?.....	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
3. Do you have problems in breathing when you are physically inactive or active?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
4. Did you ever fall down because of dizziness or have you ever lost consciousness?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
5. Do you have bone or joint problems that could be made worse when being physically active?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
6. Has a doctor ever prescribed you drugs for high blood pressure or heart or breathing problems?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
7. Do you not feeling well because of a temporary illness such as cold or fever?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
8. Are you or may you be pregnant?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>
9. Do you know of any other reason why you should not do physical activity?	<input type="radio"/> Yes <input type="radio"/> No	<input type="radio"/>

Fig. 1 ◀ Modified German version of the Physical Activity Readiness—Questionnaire (PAR-Q). (Modified from [34, 35])

ten informed consent. The study protocol was approved by the ethics committee of Charité–Universitätsmedizin Berlin and the federal data protection and freedom of information authority.

Measurement method

Selection of the test procedure

Maximal exercise tests, using spirometry to measure maximum oxygen uptake (V_{O2max}), are considered to be the reference standard to measure cardiorespiratory fitness [19]. Although maximal exercise tests are generally regarded as safe, the possibility of cardiovascular events and fatal outcomes during exertion cannot be totally excluded, as there is an increased probability of sudden cardiac death during vigorous exercise [20, 21]. The more risk factors that apply, such as high blood cholesterol or blood pressure, smoking, diabetes mellitus or a history of cardiac disease, the greater is the risk of an event [22]. In clinical settings, a risk rate of up to one per 2,500 tests can be assumed [23, 24]. Maximal exercise tests therefore require the presence of a qualified physician, a multichannel ECG, full emergency equipment and a defibrillator [19, 25]. The risk of an event among cardiac patients is only around half as great in submaximal compared to max-

imal exercise tests [23, 26]. As fewer staff and less equipment are required [19], and submaximal tests are of shorter duration, they are a cost-effective alternative to maximal tests, while providing an adequate assessment of cardiorespiratory fitness [6]. In national health studies comparable to DEGS1, such as the US National Health and Nutrition Examination Survey (NHANES) [27] or the Survey of the Fitness of Australians [28], submaximal treadmill or cycle ergometer tests were used. Assuming that the relationship between heart rate and oxygen uptake is linear, in these studies V_{O2max} was estimated based on heart rate data using the approach of extrapolation [27, 28]. Validation studies have shown that the correlation between estimated V_{O2max} in a submaximal test, and measured V_{O2max} in a maximal test, using a cycle ergometer, is high: correlation coefficients of 0.69–0.98 have been reported [29, 30]. Maximal and submaximal tests both show a high degree of reliability, with correlation coefficients of greater than 0.9 being reported [30]. In order to carry out inter-individual V_{O2max} comparisons using maximal tests, all participants must achieve a similar level of maximum exertion, which is a challenge. Submaximal tests have the advantage of being independent of subjects' motivation to achieve their individ-

ual maximum exertion level [31]. Cycle ergometers are generally cheaper, smaller and quieter than treadmills, and require less upper body movement; however, less fit individuals more often experience leg-muscle fatigue when using them [23].

Following consultation with experts and an evaluation of the risks, costs and benefits involved, and given that this was a national mobile examination survey, it was decided that in DEGS1 cardiorespiratory fitness should be measured by means of a submaximal cycle ergometer test among asymptomatic adults aged 18–64. Cardiorespiratory fitness was estimated using exertion-induced change in heart rate and blood lactate concentration. Lactate analysis, like blood gas measurement and spirometry, provides higher-quality measurements than heart rate analysis since, provided a minimum level of exertion is achieved, it does not depend on the participant's cooperation [32]. In the context of a submaximal test protocol, a lactate-based assessment of aerobic work capacity at fixed thresholds has the advantage, compared to V_{O2max} assessment, that comparisons between individuals can be made without the precondition that maximum exertion must be achieved [19], or respectively, V_{O2max} must be estimated on the basis of linearity assumptions [33].

Inclusion criteria

There is an increased risk of cardiovascular events during physical exertion in subjects with existing cardiovascular and pulmonary conditions [19, 22, 23]. A modified German version of the Physical Activity Readiness–Questionnaire (PAR-Q) [34, 35] was therefore used to screen the physical-activity readiness status of the 18- to 64-year-old participants, using nine questions to minimise the risk of events during the study (Fig. 1). The German version of PAR-Q developed by the German Society for Sports Medicine and Prevention (DGSP) [35] was used and modified in terms that two additional questions on temporary conditions such as “cold and fever”, and on “pregnancy” were added to the screening tool. In case that at least one of the nine contraindications applied to the participant, the procedure was that the participant consults the doctor who then decides whether the person is test-qualified or not. This meant that some participants, although they answered PAR-Q questions in the affirmative, they were still enrolled into the test. The criteria “heart condition and physical activity only under medical supervision”, “prescribed medication for high blood pressure or heart or breathing problems” and “pregnancy beyond the 11th week” were absolute contraindications if the participant confirmed those contraindications when seeing the doctor. To be included in the cycle ergometer test, participants were required to be aged 18–64, have signed an informed consent, and be categorised as test-qualified.

Test equipment

The following test equipment was used: a calibrated cycle ergometer with integrated blood pressure measurement and Polar heart rate monitor (Ergosana CE 0124), blood pressure cuffs (Ergosana), a heart rate transmitter (Oregon), a notebook with ergometer software (Dr Schmidt GmbH), a barcode scanner, a lactate analyser (EKF-Diagnostics, BiosenC_line), blood flow ointment, blood lancets, capillary tubes (20 µl), a defibrillator, a medical emergency box and a 20-point Rated Perceived Exertion (RPE) scale [36]. The RPE scale is often used to assess whether the participant has

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J.D. Finger · A. Gößwald · S. Härtel · S. Müters · S. Krug · H. Hölling · R. Kuhnert · K. Bös Measurement of cardiorespiratory fitness in the German Health Interview and Examination Survey for Adults (DEGS1)

Abstract

A state of good fitness is related to a better health state and a lower mortality risk. In the German Health Interview and Examination Survey for Adults (DEGS1), aerobic fitness was measured among adults between 18 and 64 years old using a submaximal cycle ergometry test. The total sample comprised 5,263 persons, amongst those 3,111 were categorized as being test-qualified according to the Physical Activity Readiness–Questionnaire. There were 3,030 persons who absolved a submaximal exercise test according to the exercise protocol of the WHO (25/25/2). The test-participation rate was 57.2% in relation to the total sample and 97.4% among test-qualified persons. Apart from the continuous heart-rate monitoring, capillary blood was taken prior to start-

ing the test and at the end of each workload stage for performing blood lactate analyses. The test ended when 85% of the age-predicted maximal heart rate was exceeded. In all 11.9% of the tests were terminated earlier, the mean exercise duration was 10.8 min, and the anticipated submaximal exertion in the highest workload stage was on average achieved with a mean of 15 on the 20-point RPE scale. The nationwide data can now be used for the national health monitoring system, epidemiological research and for the calculation of reference values.

Keywords

Cardiorespiratory fitness · Bicycle ergometry · Health survey · Adults · Germany

Messung der kardiorespiratorischen Fitness in der Studie zur Gesundheit Erwachsener in Deutschland (DEGS1)

Zusammenfassung

Ein guter Fitnesszustand ist verbunden mit einem guten Gesundheitszustand und einem geringeren Mortalitätsrisiko. Deshalb wurde in der „Studie zur Gesundheit Erwachsener in Deutschland“ (DEGS1) die aerobe Fitness mittels submaximaler Fahrradergometrie bei 18- bis 64-jährigen testtauglichen Erwachsenen ermittelt. Die Gesamtstichprobe umfasste 5263 Personen, von denen 3111 nach dem „Physical Activity Readiness–Questionnaire“ als testtauglich eingestuft wurden. 3030 Personen absolvierten einen submaximalen Belastungstest nach WHO-Protokoll (25/25/2). Die Teilnahmequote war 57,2% bezogen auf die Gesamtstichprobe und 97,4% bei den Testtauglichen. Neben der kontinuierlichen Herzfrequenzerfassung wurde vor Testbeginn und am Ende jeder Belastungsstufe

Kapillarblut für die Laktatanalyse abgenommen. Der Test endete nach Überschreiten von 85% der altersbasierten maximalen Herzfrequenz. 11,9% der Tests wurden vorzeitig abgebrochen, die durchschnittliche Belastungsdauer betrug 10,8 min, und die angestrebte submaximale Belastung der Testperson in der letzten Belastungsstufe wurde mit einem Wert von 15 auf der 20-Punkte-Borg-Skala im Mittel erreicht. Die bundesweiten Daten können für das Gesundheitsmonitoring, die epidemiologische Forschung und zur Erstellung von Referenzwerten genutzt werden.

Schlüsselwörter

Kardiorespiratorische Fitness · Fahrradergometrie · Gesundheitssurvey · Erwachsene · Deutschland

achieved target exertion during ergometry. The individual maximum exertion corresponds to a RPE scale value of equal or greater than 17 [37].

Standardised test procedure

The participant was informed about the test procedure and positioned on the ergometer. Blood flow ointment was put on the earlobe, and the moistened heart-rate transmitter and blood pressure cuff

were put in place. The individual target heart rate was computer-assisted calculated with the formula $0.85 \times (220 - \text{age})$ [38]. The baseline lactate level was assessed using 20 µl of capillary blood taken from the earlobe. The software-based test programme started by measuring the baseline heart rate and blood pressure. Following the WHO protocol [39], the exercise test began with a workload of 25 watts (W) and the software automatically increased

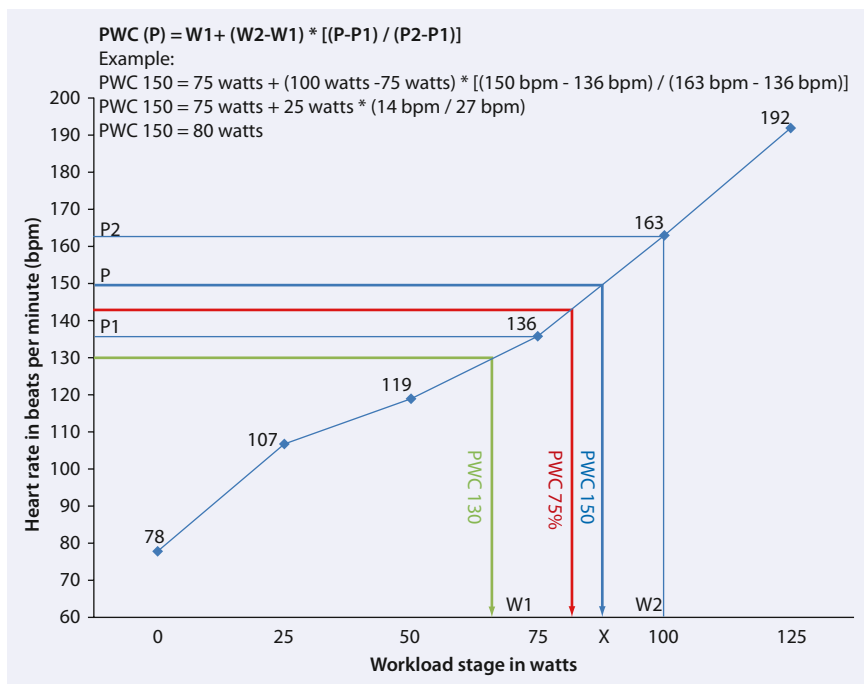


Fig. 2 ▲ Calculation of the Physical Work Capacity (PWC) based on fixed and variable heart-rate thresholds

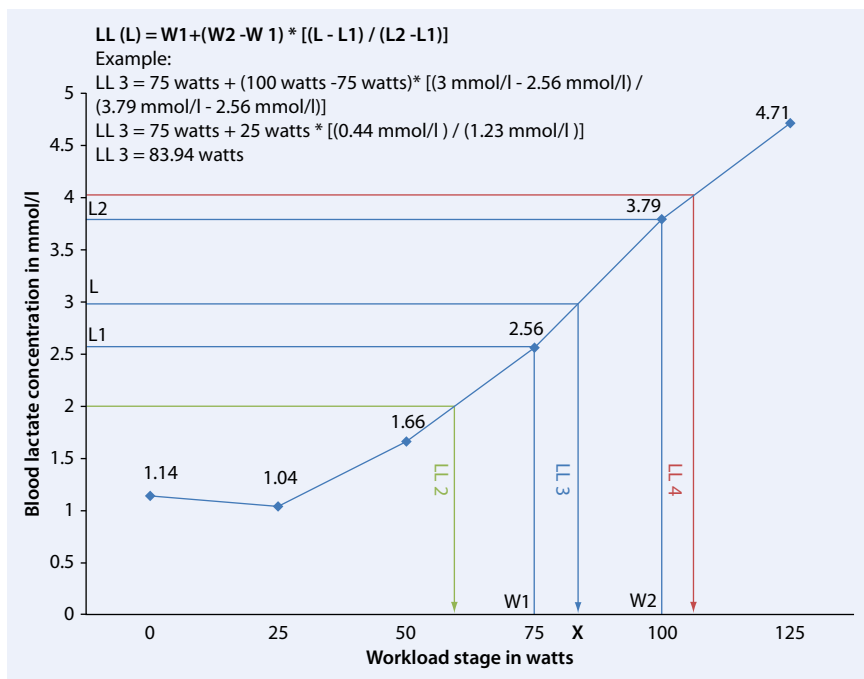


Fig. 3 ▲ Calculation of the lactate-based work capacity at the 2,3 and 4 mmol/l lactate thresholds

the workload by 25 W every 2 min. Participants were requested to maintain a pedal-revolution rate of 70 revolutions per minute (rpm) as consistently as possible [32, 40], and their heart rate was continuously recorded. Blood pressure was automatically measured 1 min after mov-

ing to each new workload stage, and capillary blood was taken at the end of each workload stage. When the individual target heart rate was exceeded for more than 30 s, the final workload stage was reached. At the end of the highest stage, the participant rated the perceived exertion us-

ing the RPE scale [36]. After this stage, the software switched to a 5-min, performance-neutral recovery period in which the blood pressure was measured three more times and the heart-rate recovery was recorded. The blood lactate samples were analysed after the last blood sample was taken. An initial heart-rate-based rating of aerobic work capacity was software-assisted calculated based on the table of reference values from Rost and Hollmann [41] and notified to the participant after the test.

Indications for terminating exercise testing

The applied termination criteria [19, 40, 42] were decreasing heart rate despite increasing exertion (for more than 30 s), blood pressure over 220 mmHg systolic or 120 mmHg diastolic, drop in systolic blood pressure of >10 mmHg from baseline blood pressure, chest pain or a feeling of constriction in chest, signs of poor perfusion, shortness of breath, headache, dizziness, sight problems, subjective exhaustion, leg fatigue, leg cramps, a pedal-revolution rate below 60 rpm, or technical difficulties to monitor heart rate or blood pressure.

Concepts of data analyses

Heart-rate-based analysis

The concept of Physical Work Capacity (PWC) [31, 43] was used to analyse the participant's aerobic work capacity based on heart-rate data. According to the concept, the PWC is calculated at the heart-rate thresholds of 130 and 150 beats per minute (bpm), and the obtained PWC is then divided by the participant's bodyweight. In the age group 44 years and older, the individual target heart rate in submaximal exercise tests is lower than 150 bpm, therefore, for this age group only the PWC₁₃₀ can be calculated for methodological reasons. The higher the bodyweight-related PWC values are the better is the subsequent rating of the participant's aerobic fitness. Since the recorded heart-rate values do usually not exactly correspond to the heart-rate thresholds (130, 150 bpm), PWC₁₃₀ and PWC₁₅₀ were calculated using the mathematical approach of linear interpolation by ap-

Tab. 1 Proportion of test-unqualified^a participants after consulting the physician, by age and sex

Age group	18–29		30–39		40–49		50–64		Total	
	n	% (95%CI)	n	% (95%CI)	n	% (95%CI)	n	% (95%CI)	n	% (95%CI)
Sex										
Women	110	20.1 (16.8–23.5)	98	22.7 (18.7–26.7)	227	32.6 (29.1–31.1)	585	53.1 (50.1–56.0)	1,020	36.7 (34.9–38.5)
Men	67	12.8 (9.9–15.6)	76	18.5 (14.8–22.3)	179	29.8 (26.2–33.5)	494	51.9 (48.7–55.1)	816	32.8 (31.0–34.7)
Total	177	16.5 (14.3–18.8)	174	20.7 (17.9–23.4)	406	31.3 (28.8–33.9)	1,079	52.5 (50.4–54.7)	1,836	34.9 (33.6–36.7)

^aTest-unqualified based on the modified German version of the Physical Activity Readiness Questionnaire (PAR-Q)

95%CI 95% confidence interval.

Tab. 2 Distribution of the reasons (more than one reason per excluded case possible) which resulted in test exclusion according to the modified German version of the Physical Activity Readiness–Questionnaire (PAR-Q), stratified by sex

Women (n=2,610)				Men (n=2,337)				Test-unqualified according to physician ^c (n=1,836)	
Positive replies ^a		Retracted by physician ^b		Positive replies ^a		Retracted by physician ^b		n	%
n	%	n	%	n	%	n	%		
Contraindications									
Physical activity under supervision									
216	8.3	45	20.8	224	9.6	45	20.1	350	19.1
Chest pain when being (in)active									
332	12.7	121	36.4	253	10.8	106	41.9	358	19.5
Problems in breathing									
551	21.1	188	34.1	342	14.6	113	33.0	592	32.2
Ever fallen down due to dizziness									
539	20.7	301	55.8	317	13.6	164	51.7	391	21.3
Bone or joint problems									
806	30.9	316	39.2	642	27.5	280	43.6	852	46.4
Prescribed medication ^d									
731	28.0	110	15.0	647	27.7	91	14.1	1,177	64.1
Temporary not feeling well									
247	9.5	53	21.5	134	5.7	25	18.7	303	16.5
Probably or definitely pregnant									
32	1.2	7	21.9	–	–	–	–	25	1.4
Other contraindications									
147	5.6	22	15.0	136	5.8	17	12.5	244	13.3

^aNumber and proportion of positive replies to PAR-Q contraindications based on self-completed PAR-Q^bNumber and proportion of contraindications retracted by physician^cNumber and proportion of valid contraindications in relation to the finally test-unqualified men and women (more than one exclusion reason per case is possible)^dPrescribed medication for high blood pressure or heart or breathing problems.

plying the formula published by Rost and Hollmann ([41], [Fig. 2](#)).

Maximum heart rate continuously decreases with increasing age, however [38]. This circumstance becomes a problem if PWC is compared across age groups at fixed heart-rate thresholds. For instance, a heart rate of 150 bpm corresponds to approximately 75% of the age-predicted maximum heart rate in a 20-year-old person, and to 96% in a 64-year-old person. In the context of population-based studies, this leads to the problem that aerobic fitness levels of younger people

are underestimated compared to those of older people [28]. Instead of using “fixed” heart-rate thresholds for group comparisons, “variable” thresholds can alternatively be used to solve this problem. PWC can also be calculated at an individual heart rate of 75% of the age-predicted maximum heart rate ($PWC_{75\%}$) [28]. Individual heart-rate thresholds can be calculated with the formula $0.75 \times (208 - 0.7 \times \text{age})$ [38]. $PWC_{75\%}$ can then be calculated at the obtained individual heart-rate threshold using graphic or arithmetical interpolation ([Fig. 2](#)).

Concepts based on “variable” thresholds are preferable to those of “fixed” thresholds when carrying out cross-sectional analysis, as they adjust for the age-related decrease in maximum heart rate [28].

Both procedures were used to analyse the DEGS1 data. $PWC_{130, 150}$ are needed to compare the DEGS1 data to Rost’s and Hollmann’s PWC reference values and $PWC_{75\%}$ to carry out cross-sectional analyses.

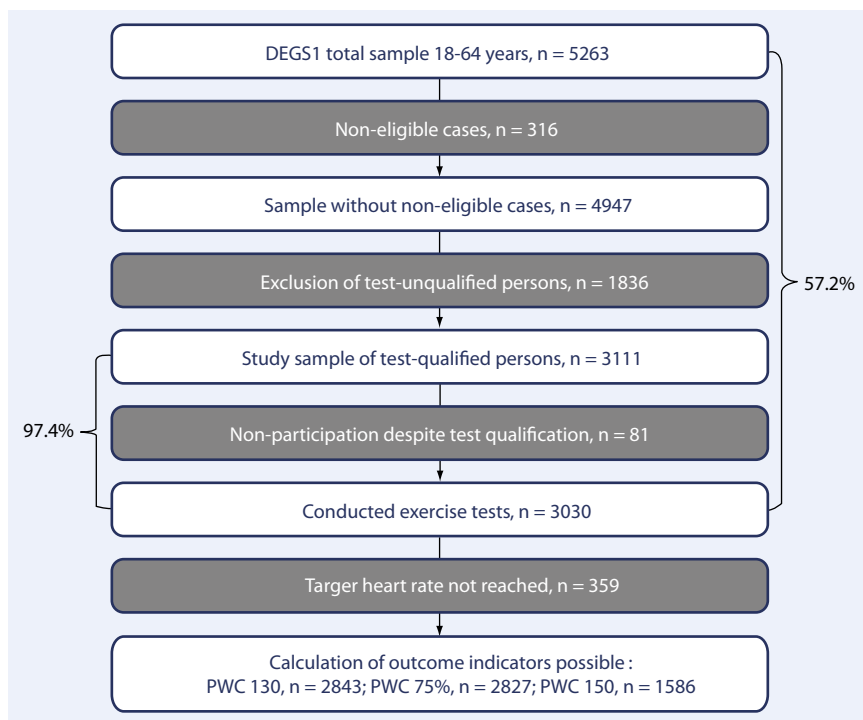


Fig. 4 ▲ Calculation of test-participation rates based on the total sample and the study sample

Lactate-based analysis

In order to analyse the blood lactate data, the underlying principal of the PWC concept is applied to the blood lactate data. Lactate thresholds of 2, 3 and 4 mmol/l can possibly be used as the basis, where the lactate-based work capacity is calculated and individuals compared with each other. Using the already mentioned formula of linear interpolation [41], lactate-based work capacity can be calculated at the 2, 3 and 4 mmol/l thresholds (■ Fig. 3) and subsequently be divided by the participant’s body-weight. Furthermore, comparisons can also be made at “variable” lactate thresholds, such as the “individual anaerobic threshold” [44, 45].

Results

Test exclusions, terminations and participation rates

The total DEGS1 sample of 18- to 64-year-old participants, who were examined and interviewed, consisted of 5,263 persons. There were 316 persons (6.0%) who were classified as non-eligible cases, because for them exercise testing was not possible for technical or organisational reasons.

Another 1,836 persons (34.9%) were excluded, since they were categorised as being test-unqualified by the physician. The probability of exclusion from the cycle ergometer test increased with age, and women were more often excluded than men (■ Tab. 1). The PAR-Q exclusion criterion “prescribed drugs for high blood pressure or heart or breathing problems”, was the most frequent contraindication indicated by excluded persons. The potential PAR-Q exclusion criteria “ever lost balance/consciousness because of dizziness”, “bone or joints problems”, and “chest pain when being physically inactive or active” were the contraindications which were most often retraced by the physician when the participant saw the doctor due to a positive PAR-Q (■ Tab. 2).

The final study sample for the cycle ergometer test consisted of 3,111 test-qualified persons: 1,521 men and 1,590 women. A total of 81 persons were not tested although being test-qualified. The most common reasons for this were refusal (n=25), problems with communication (n=12) and lack of time (n=8). In all 3,030 persons were finally tested. Of these, 359 (11.9%) terminated the test before reaching the individual target heart rate, most

commonly due to subjective exhaustion (n=201), exceeding blood pressure limits (n=93), technical problems (n=78), and pallor, shortness of breath, dizziness or headache (n=9). Cardiovascular events were not registered.

The test-participation rate was 97.4% in relation to the study sample of test-qualified persons, 61.2% in relation to the total sample excluding non-eligible cases, and 57.2% in relation to the total sample. It was possible to calculate the weight-related PWC₁₃₀ for 2,843 persons, the PWC_{75%} for 2,827 and the PWC₁₅₀ for 1,586 (■ Fig. 4).

Test duration, number of workload stages and rated perceived exertion

The average exercise duration was 10.8 min. Including the 5-min recovery period and test instructions, the total test duration was about 15–20 min. The maximum amount of workload stages being achieved was 12, which is equal to 300 W.

Participants completed on average of 5.4 stages which is equal to a workload of 135 W. The mean rated perceived exertion according to the RPE scale [36] in the last stage was 14.9 for women and 15.0 for men, which corresponds to a “strenuous/hard” rated perceived exertion.

Discussion

Test qualification and subject safety

The test-exclusion rate because of conditions or symptoms according to modified PAR-Q was 34.9%. The test-exclusion rate was higher in older than in younger age groups. The expected test-exclusion rate of about one third of the participants, which was previously assumed on the basis of disease-prevalence data from the German health monitoring system (GBE), was thereby slightly exceeded. According to the 2009 German Health Update study (GEDA09), the prevalence of chronic disease was about 33% in 18- to 64-year-old persons, which was also higher in higher than younger age groups [46]. Also the proportion of 28% of the participants who reported that “a doctor

prescribed drugs for high blood pressure or heart or breathing problems” complies approximately with the 12-month prevalence of high blood pressure according to GEDA09, which is about 26%.

The test was designed to achieve a high data quality and to minimise the risk of cardiovascular events at the same time. The mean rated perceived exertion at the end of the last workload stage in DEGS1 was about 15 (“strenuous/hard”) on the RPE scale [36] which corresponds to a submaximal exertion, as it was intended by the study design. At the same time, no cardiovascular events occurred during the study. Thus, by achieving on average a submaximal exertion, moreover, avoiding cardiovascular events at the same time, the intended balance between adequate physical exertion and subject safety was achieved in this study.

Internal and external validity

A comparable high level of internal validity can be assumed for the objective parameters obtained in this study, considering the fact that in population-based studies mostly only self-reported information on physical activity and fitness are obtained [3]. The decision to use a submaximal test protocol and to estimate cardiorespiratory fitness based on heart rate data conforms to the standard which was used in comparable national health studies [27, 28]. Compared to the reference standard of measuring V_{O2max} in maximal tests, a reduced validity must be assumed when estimating aerobic fitness based on heart-rate data in submaximal test, with correlation coefficients of 0.69–0.98 being reported [29, 30]. Heart-rate parameters are considered to be less valid than oxygen-uptake and lactate parameters, since the heart rate is influenced by age, sex, fitness level, body temperature, ambient temperature and vegetative factors [47], which are responsible for an increased heart-rate variation. The additional assessment of lactate parameters adds value to this study compared to national health studies in other countries, since lactate as well as oxygen-uptake are both considered as valid parameters to measure aerobic work capacity [47].

The results can be generalised to test-qualified adults aged 18–64. The generalisability for the total population in this age group is however limited due to the positive selection of participants on the basis of modified PAR-Q. It can be assumed that test-unqualified participants have a lower cardiorespiratory fitness than those who are test-qualified. Studies have shown that high cardiorespiratory fitness level is associated with a lower prevalence of high blood pressure [48]. As high blood pressure increases the probability to be excluded from the test, it is likely that cardiorespiratory fitness is lower in the total population than in the population of test-qualified persons. This selection bias is greater in older age groups, as the proportion of unqualified participants is higher in older than younger age groups.

Outlook

The currently recommended national PWC reference values for Germany [8, 40, 42, 47] were first published about 30 years ago on the basis of a relatively small, non-randomised sample of 123 men and an unspecified number of women, consisting of untrained adults who attended the research institute of the working group [41]. As far as we know, there are no national reference values available on lactate-based assessment of aerobic work capacity [49]. DEGS1 enables the calculation of up-to-date PWC and lactate reference values based on a nationwide sample. It is planned to compare the objective information on cardiorespiratory fitness with the self-reported information on physical activity and to conduct cross-sectional analysis on the associations between cardiorespiratory fitness and other health-related variables assessed in DEGS1. Apart from sociodemographic variables, a wide range of health indicators were obtained in DEGS1 [14], which offers various opportunities to investigate associations between cardiorespiratory fitness and health. It is also planned to follow the DEGS1 participants over time and to use the same test method in future surveys again, which will give the opportunity to conduct tracking, trend

and prospective studies on cardiorespiratory fitness in future.

Conclusion

Due to the increasing importance of aerobic physical activity in preventive medicine and health promotion, the objective assessment of aerobic fitness can be seen as a reasonable supplementation of the test and examination spectrum of DEGS. The applied assessment strategy complies with the standards used in national health studies in other countries. The test-exclusion rate of about 35% is in the range of the prevalence of as contraindications defined symptoms and conditions in the investigated age group. Some participants who were screened as test-unqualified according to modified PAR-Q in the first place could be still enrolled into the test after consultation with the physician. The validity of heart-rate parameter in submaximal exercise tests is lower than that of oxygen-uptake parameter in maximal exercise tests. In the context of national health studies however, in which for the most part self-reports on physical activity and fitness are obtained, the heart rate-based objective assessment of fitness poses a gain in validity to the data quality. The additional assessment of blood lactate concentration adds additional value to the study, since lactate parameter allow a valid assessment of aerobic fitness. Nationwide data on cardiorespiratory fitness for test-qualified adults in the age group 18–64 are now available with DEGS1, which can be used for the national health monitoring system, epidemiological research as well as for calculating national reference values.

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