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Henriksson, H., Henriksson, P., Tynelius, P., Ortega, F. B, (2019), Muscular weakness in adolescence is associated with disability 30 years later: a population-based cohort study of 1.2 million men, *British Journal of Sports Medicine*, 53(19), 1221. <https://doi.org/10.1136/bjsports-2017-098723>

Original publication available at:

<https://doi.org/10.1136/bjsports-2017-098723>

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Muscular weakness in adolescence is associated with disability 30 years later: a population based cohort study of 1.2 million men

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Running title: Adolescent muscular weakness is associated with later disability

What are the new findings?

- In this large cohort study that included data from 1 212 503 male adolescents, muscular weakness was associated with later risk of obtaining disability pension.
- The strongest associations were found between muscle weakness and psychiatric and nervous system causes of disability pension, with hazard ratios ranging from 1.47 to 1.68 (95% confidence intervals from 1.41 to 1.88).
- Muscle weakness in combination with being aerobically unfit and/or obese was associated with the highest risk of later disability pension. For instance, being concurrently weak, unfit and obese was associated with a 3.70-fold (95 % confidence interval, 2.99-4.58) greater risk of disability pension approximately 30 years later.

How might it impact on clinical practice in the near future?

- Muscular weakness in youth is associated with disability approximately 30 years later.
- Muscular weakness in combination with low aerobic fitness and/or obesity was an especially strong risk factor for later disability.
- This study adds weight to the case for promoting muscular strength and aerobic fitness in adolescence.

ABSTRACT

Objective: To investigate the associations of muscular strength in adolescence with later disability pension (DP), across different body mass index categories and in combination with aerobic fitness.

Method: This prospective cohort study consisted of males aged 16-19 years, recruited from the Swedish military conscription register between 1969-1994. A total of 1 212 503 adolescents met all the inclusion criteria and were therefore included in the analyses. Knee extension, handgrip, and elbow flexion strength and aerobic fitness (bicycle ergometer test) were measured during conscription. Causes of disability pension were retrieved from the Social Insurance Office between years 1971-2012 (average follow-up time: 29.6 years).

Results: Knee extension strength in adolescence was inversely associated with men's risk of obtaining DP due to all-causes (HR, 1.40, 95% CI, 1.36-1.44 for lowest vs. highest strength quintile). Thus, muscular weakness was associated with disability pension. The risk associated with low muscular strength differed between specific causes of DP and the strongest associations were found for psychiatric, nervous system and other causes (HRs between 1.47-1.90 for lowest vs. highest quintile). Being strong was associated with lower DP risk across BMI categories and being unfit, weak and obese was associated with the highest DP risk (HR, 3.70, 95% CI, 2.99-4.58).

Conclusion: There was a strong association between muscular weakness and disability. A combination of muscular weakness and low aerobic fitness was an especially important risk factor for disability. This adds weight to call for muscular strength and fitness enhancing exercise for adolescents in all BMI categories.

INTRODUCTION

Chronic diseases and injuries leading to premature mortality and disability constitute a major concern for society and have major clinical and economic consequences^{1,2}. An objective and reliable way to study the incidence of the most prevalent chronic diseases and injuries in adulthood is using data on disability pension (DP). In the Nordic countries, DP is granted if a person is likely to never work full-time again due to severe chronic disease or injury. Morbidity as indicated by DP severely affects the quality of life for a large number of individuals, and is a great economic burden on society³.

Moderate to high muscular strength at a young age is a powerful determinant of health^{4,5}. There is an inverse association between muscular strength and adiposity, cardiovascular disease and metabolic risk factors in youth⁶. Poor muscular strength in adolescence is also associated with cardiovascular disease later in life⁷, as well as premature death due to all-causes, suicide and cardiovascular disease⁸. However, little is known about the association of muscular strength with all-cause and cause-specific morbidities as indicated by DP. One previous study reported that handgrip strength in absolute values was not related to DP due to musculoskeletal disorders, but there was an inverse association between handgrip/body weight ratio and DP risk⁹. However, there are no studies about the association of other measures of muscular strength with DP. Also, little is known about the association between muscular strength and other causes of DP, other than musculoskeletal.

Obesity and high aerobic fitness in youth have been associated with higher¹⁰ and lower¹¹ risk of DP, respectively. Considering that obesity (especially severe-morbid obesity, class 2-3), compared to normal-weight, is associated with considerably greater risk of later DP¹¹, it is of great

importance to identify factors, such as high muscular strength, that is associated with a lower DP-risk in obese youth. However, it is unknown whether high muscular strength may attenuate the negative influence of obesity, especially severe-morbid obesity, on the risk of obtaining DP. It has previously been shown that a combination of low aerobic fitness and muscular strength is associated with mortality risk^{12,13}, but it is not known if a combination of low muscular strength and aerobic fitness is related to DP risk.

We followed up more than 1.2 million male adolescents from the Swedish military conscription register between 1969 and 1994, which provides enough power to investigate associations with specific causes of DP. Thus the aims of this study were to investigate: 1) the association between muscular strength and DP for all-causes and specific causes, 2) whether higher muscular strength is associated with a lower risk of DP in different body mass index (BMI) categories and 3) the combined association of muscular strength and aerobic fitness on DP risk.

METHODS

Study sample

We used the Swedish Multi-Generation Register to identify a total population of males born in Sweden between 1951 and 1976. By using a unique personal identification number assigned to all Swedish citizens a linkage was created to the Swedish Military Conscription Register as well as other nation-wide registers. During the years covered by this study, conscription examination was mandatory by law for all young males in Sweden and only 2-3 % of adolescents with severe chronic diseases were exempted. Inclusion criteria were age ≤ 19 years and availability of valid data on muscular strength, BMI and other covariates. Of a total population of 1 396 605 males, 1 236 800 males aged ≤ 19 years attended conscription. Those without of valid data of strength

(n=16 918), BMI (n=1508) and other covariates (n=5267) were excluded from the analysis.

Furthermore, in accordance with previous studies from the Swedish conscription data, adolescents with extreme values for height (valid range: 150-210 cm), weight (valid range: 40-150 kg) and body mass index (valid range: 15-60) were excluded (totally n=604). Hence, a total of 1 212 503 male adolescents (86.8 % of the total population) aged 16 to 19 years met inclusion criteria and were therefore included in the analyses. The study was approved by the Regional Ethics committee, Stockholm, Sweden.

Baseline measurements

Knee extension strength, handgrip strength and elbow flexion strength were measured during conscription as previously described^{7,8,14}. Handgrip strength was measured with the hand in a vertical position, with 90 degrees flexion at the elbow. Elbow flexion and knee extension were measured in a sitting position with 90 degrees flexion over the main joint. These muscular strength tests are reliable in young men ($r=0.88-0.98$)¹⁵. Aerobic fitness was measured with a maximal workload test using a bicycle ergometer, as previously described^{11,16,17}.

BMI was calculated as weight in kilograms divided by the square of height in meters, using standardized height and weight measurements. Classification of BMI was performed according to World Health Organization (WHO) criteria (underweight: $< 18.5 \text{ kg/m}^2$, normal-weight: $18.5-24.9 \text{ kg/m}^2$, overweight: $25.0-29.9 \text{ kg/m}^2$, obesity class I: $30.0-34.9 \text{ kg/m}^2$, obesity class II: $35.0-39.9 \text{ kg/m}^2$, obesity class III: $\geq 40.0 \text{ kg/m}^2$).

Disability pension

Dates and codes for the cause of DP according to International Classification of Diseases (ICD) 8, 9, or 10 was retrieved from the Social Insurance Office between years 1971-2012.

Supplementary table 1 shows utilized ICD codes. The diagnosis granting a DP had to be confirmed by a certificate from a physician. A person whose working capacity is chronically reduced by at least 25% due to illness or injury may be granted DP, according to the Swedish law. We studied the major causes of DP: psychiatric (e.g. anxiety disorders, depressive episode), musculoskeletal (e.g. dorsalgia, soft tissue disorders), injuries (e.g. dislocation, sprain and strain of joints and ligaments), nervous system (e.g. multiple sclerosis), circulatory (e.g. cerebrovascular diseases and ischemic heart diseases) and tumors which together constitute about 90 % of all granted DP's in Sweden¹⁰. DP due to other causes than the aforementioned were classified as DP due to "other causes".

Confounders

The following confounders were considered in this study: childhood socioeconomic position (SEP), age at conscription, conscription center and conscription year. Information about childhood SEP was obtained from the Population and Housing Censuses from 1960-1990, and these censuses were conducted every fifth year. Childhood SEP was categorized into seven levels and we used the highest level of either parent.

Statistical analysis

Cox proportional hazards regression models were used to estimate hazard ratios (HR) and 95% confidence intervals (95% CI). All models were adjusted for childhood SEP, age at conscription, conscription center and conscription year and additional adjustment for BMI was performed in

Figures 1, 2 and 4. Furthermore, all analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription. Men who died or emigrated during the follow-up were censored at the date of the death or emigration, respectively. Additionally, in the analysis with specific causes of DP, participants with DP due to another cause were censored at the date of DP. To investigate associations of muscular strength with DP, muscular strength was categorized into quintiles and cut-offs and sample sizes for each quartile are found in the footnote of **Table 1**. For the analyses, adolescents in the lowest quintile (quintile 1) were considered as “Weak” while adolescents in quintiles 2 to 5 were considered “Strong”. Similarly, adolescents with fitness in the lowest quintiles were defined as “Unfit” whereas adolescents in quintiles 2 to 5 were defined as “Fit”, as in previous articles^{18,19}. Statistical analyses were performed using SPSS Statistics 22 (IBM, Armonk, NY, USA).

RESULTS

Table 1 shows the baseline characteristics of the whole study cohort. A total of 1 212 503 men were followed for an average time of 29.6 ± 7.7 years (range 0.02-43.3) and during this time 69 248 men (5.7 %) were granted DP due to a medical condition. Mean age for obtaining DP was 42.2 ± 8.4 years. Low muscular strength was associated with higher risk of DP due to all-causes, as shown in **Figure 1** (detailed information is provided in **Supplementary table 2**). The association was strongest for knee extension strength (HR, 1.40, 95% CI, 1.36-1.44 for lowest vs. highest strength quintile), followed by handgrip strength (HR, 1.22, 95% CI, 1.19-1.25), and showed the weakest associations for elbow flexion strength (HR, 1.09, 95% CI, 1.06-1.12), both in the basic model and with additional adjustment for BMI. In a sensitivity analysis, we re-ran our models excluding men who obtained DP during the first 10 years of follow-up and the results

remained similar. Thus, knee strength was associated with DP due to all-causes when excluding men who obtained DP the first 10 years of follow-up (HR, 1.36, 95% CI, 1.33-1.40 for lowest vs. highest quintile in fully adjusted model) which is quite similar to our original results (i.e. HR, 1.40, 95% CI, 1.36-1.44). Furthermore, excluding men with mental hospitalization and psychiatric diagnosis at conscription instead of adjusting for these conditions yielded very comparable results.

Knee extension muscular strength and specific causes of DP

In order to avoid presenting all the information in triplicate, the main analyses are shown for knee extension, which was the most powerful indicator of health-related muscular strength in this study. Associations of handgrip strength with specific causes of DP can be found in **Supplementary table 3**. Associations of knee extension muscular strength (5 strength levels) with specific causes of disability pension are shown in **Figure 2** (detailed information is provided in **Supplementary table 4**). Overall, comparable trends but of smaller effect sizes were observed for handgrip compared with knee extension for most of models studied except for DP due to musculoskeletal and injuries causes (see Supplementary table 3 and 4). In the basic models, knee extension muscular strength was associated to DP due to psychiatric, nervous system and other causes, but not to musculoskeletal, injuries, circulatory or tumors causes. After additional adjustment for BMI, muscular strength was also associated to DP due to musculoskeletal and circulatory causes and weakly to DP due to injuries. The association was particularly strong for DP due to the nervous system (HR, 1.68, 95% CI, 1.51-1.88), psychiatric causes HR, 1.47, 95% CI, 1.41-1.53) and other causes (HR, 1.90, 95% CI, 1.75-2.07).

Knee extension strength and disability pension across BMI categories

As shown in **Figure 3** (detailed information in **Supplementary table 5**) we investigated associations between knee extension muscular strength and disability pension throughout BMI categories. The analyses were conducted for DP due to all-causes and for psychiatric and musculoskeletal causes since they are the two most prevalent causes of DP. Strong men (i.e. quintiles 2 to 5) had a lower risk of disability pension than weak men (quintile 1) across BMI categories, but the associations did not reach statistical significance for obesity level 2-3 for all-cause DP and for obesity level 1 and 2-3 for DP due to psychiatric and musculoskeletal causes.

Combination of knee extension muscular strength and aerobic fitness with risk of disability pension

We also investigated associations of the combination of knee extension strength and aerobic fitness with DP due to all-cause, psychiatric and musculoskeletal causes, as shown in **Figure 4** (detailed information in **Supplementary table 6**). The combination of being both aerobically unfit and weak was associated with the highest risk of DP for the investigated causes. The greatest DP risk was due to psychiatric causes for men who were both aerobically unfit and weak (HR, 1.89, 95% CI, 1.82-1.97). Finally, as shown in **Figure 5** being fit and strong attenuated the risk of DP in both the normal-weight and obese group (obesity classes 1-3). Similar trends were obtained for underweight and overweight subgroups and can be found in **Supplementary table 7**.

DISCUSSION

We highlight three findings relevant for clinical practice and preventive public health actions.

Firstly, muscle weakness in adolescence was consistently associated with men's risk of obtaining DP due to all-causes and associations were most pronounced for weakness in knee extension followed by weakness in handgrip. Also, the risk associated with muscular weakness differed greatly among specific causes of DP; the strongest associations were found for DP due to nervous system or psychiatric conditions and the group characterized as 'other' causes. Secondly, muscular strength appeared to mitigate the risk of DP across different BMI categories. Thirdly, a combination of muscle weakness and poor aerobic fitness jointly increased the risk of DP.

Knee extension muscular strength as a risk factor for disability pension

In this study, the associations between muscular strength and the risk of obtaining DP due to all-causes were more pronounced for knee extension and handgrip strength than for elbow flexion.

Our results extend findings by Ortega et al.⁸ who reported that the association between premature death and muscular strength was stronger for knee extension and handgrip strength than for elbow flexion strength. The handgrip test and tests of lower body strength are the most reliable, valid, and health related muscular strength tests²⁰. Therefore, we conclude that the elbow flexion strength is not a good measure for early screening of disease.

Previous studies indicate that muscle weakness is a relatively insignificant risk factor for musculoskeletal disorders^{21,22}. Only one previous study, by Ropponen et al.⁹ using Swedish conscription data, reported the association between muscle weakness and DP. The authors reported an association between handgrip strength /body weight ratio and DP risk, although associations with handgrip strength in absolute values were considerably weaker. In fact, there

was evidence that the highest quintile of handgrip strength had increased risk of DP due to musculoskeletal disorders which agrees well with our supplementary analyses (Supplementary table 3). The results by Ropponen et al. may also be reconciled with the results from our main analysis, i.e. knee extension muscular strength is not associated with an increased risk of DP due to musculoskeletal causes unless additionally adjusted for BMI. This finding might be explained by the previously reported associations of BMI with muscular strength¹⁴ as well as DP risk^{3,10}. Since we also investigated the associations of knee extension strength with all-cause DP and other specific causes of DP, we could present novel findings showing that muscle weakness was associated with DP due to all-cause, nervous system, psychiatric causes and other causes, and after additional adjustment for BMI also with musculoskeletal, injuries and circulatory causes.

The lack of studies regarding DP makes it difficult to discuss our results in relation to previous literature. However, a low level of muscular strength has been shown to be associated with all-cause premature mortality to a similar extent as classic risk factors such as obesity and hypertension⁸. In youth, there is strong evidence for an inverse association between muscular strength and adiposity, cardiovascular disease and metabolic risk factors⁶. Lower levels of muscular strength in adulthood is associated with higher risk of cardiovascular disease^{23,24} and cancer²⁵. In our study, we found associations between knee extension muscular strength and DP due to circulatory causes (after additional adjustment for BMI), but not for DP due to tumor causes, as shown in Figure 2. Noteworthy, several other authors have stressed the potential beneficial role of muscular strength on health outcomes²⁶⁻²⁸. Interestingly, these articles have also highlighted the promotion of muscular strength early in life²⁷, for obese youth²⁸ and the need of public health initiatives²⁶.

Psychiatric disorders are a major public health problem in many countries²⁹. In our study psychiatric cause was the most frequent cause of DP (43%). Therefore, it is important to identify risk factors for these conditions as early as possible to identify adolescents at great risk of later disability and to create preventive strategies. The evidence for positive effects of exercise on depression and anxiety is growing^{30,31} and one previous study showed that low muscular strength was associated with suicide mortality and psychiatric diagnosis in adolescence⁸. This is in agreement with our findings that muscular strength is associated with DP due to psychiatric causes and also extends on the finding by Ortega et al. by exploring the joint associations of strength and aerobic fitness.

The potential mechanisms underlying the association between muscular strength and DP due to psychiatric causes remain poorly understood. Nevertheless, low muscular strength has been found to be related to lower self-esteem^{6,32-34}. Therefore, it has been suggested that people with low muscular strength have worse self-esteem, which may lead to a higher risk of psychiatric disorders^{8,35,36}. Furthermore, recent evidence indicate that resistance exercise training is related to improved anxiety symptoms^{37,38}. Possible mechanism that underlie this association include thermogenic responses³⁷, neurological mechanisms³⁷ and alterations in hypothalamic pituitary adrenal (HPA) axis function³⁸. Interestingly, we observed only weak, or inverse, associations of knee and handgrip muscular strength with DP due to musculoskeletal causes and injuries, which together constitute about 34 % of all DP. These weak and/or inverse associations are intriguing and further studies are needed to clarify the role of strength and later DP due to musculoskeletal causes and injuries.

Low aerobic fitness has been proposed as a risk factor for premature mortality^{39,40}. In our study, being both aerobically unfit and weak was associated with higher risk of obtaining DP (Figure 4). Importantly, a combination of muscular weakness and low aerobic fitness was related to a higher risk of DP than the conditions alone, especially for DP due to psychiatric causes. Our study provides new evidence for the association of a combination of high muscular strength and aerobic fitness at a young age with risk of future disease exhibited as DP.

It is well known that obesity increases the risk of DP^{3,10,41}. In this article, we have examined the “fat but fit” concept⁴² in relation to DP (i.e. individuals whom are strong and aerobically fit, in spite of being obese, have a lower risk of DP). One interesting finding in this context was that being normal weight but weak was associated with a greater risk of DP due to psychiatric causes than being obese class 1 but strong, as shown in Figure 3. Also, as seen in Figure 5, normal weight but unfit and weak adolescents had only slightly lower risk of DP due to all-causes than adolescents that were obese but fit and strong. Our results indicate that muscular strength and aerobic fitness may attenuate the increased risk of obesity on DP risk.

Limitations and strengths

A major limitation of the study is its prospective cohort design which does not prove causality. Thus, although a combination of muscular strength and aerobic fitness was associated with later DP risk, these associations may be explained by unmeasured confounders. Although this study did adjust associations for several important potential confounders such as socioeconomic status, conscription age, year and center as well previous psychiatric diagnosis and hospitalization, we lack data regarding smoking and other health behaviors. For instance, smokers may have lower strength and fitness as well as greater DP risk which indicate that smoking could be a potential

confounder. Noteworthy, aerobic fitness and muscular strength has been reported to be only 7⁴³ and 2.9⁴⁴ % lower in young male smokers compared with nonsmokers and may thus not be a large confounding factor. Nevertheless, future studies on this topic should measure and account for important health behaviors (such as smoking, alcohol consumption, diet and physical activity) as well as other potential confounders.

Another limitation of this study is that it is based on military conscription data, and hence we only have data of muscular strength for male adolescents and their later risk of DP. Therefore, we cannot know to what extent our findings apply to women. An association between handgrip strength and all-cause mortality have been reported in both women and men⁴⁵⁻⁴⁷, suggesting that our results might be applicable to women as well.

We highlight three strengths of the study. 1. Our large sample size provides high statistical power. This allowed us to study risk of DP for specific causes, in different BMI categories and also to investigate the combined effect of muscular strength and aerobic fitness on DP risk. 2. The study was population-based and data for both muscular strength and DP were objectively assessed. This eliminated the risk of measurement error, non-response and selection bias due to self-reporting. 3. We measured muscular strength of participants during adolescence, when the prevalence of chronic disease is very low; outcomes were measured many years later. This study design reduces the risk of reverse causation, i.e. reduced muscular strength due to disease.

Clinical and public health implications

DP is an indicator of severe morbidity and is a great burden not only on a personal level, due to decreased quality of life, but also at the societal and economical level due to productivity losses³.

Therefore, a decreased prevalence of DP is highly relevant from a public health perspective. The evidence for beneficial associations of both muscular strength and aerobic fitness on the risk of DP suggests these capacities should be addressed by increased physical activity at young ages.

Our results suggest that a combination of high muscular strength and aerobic fitness is related with an attenuation of the excess DP risk associated with obesity. Physical fitness may thus be of special importance in the obese population. Nevertheless, a combination of high muscular strength and fitness was associated with lower DP risk also in normal weight men. Importantly, further studies including randomized controlled trials are needed to elucidate the role of muscular strength and fitness on later DP. If the reported associations prove to be causal, disability prevention should begin early in life and combine aerobic fitness and muscular strength enhancing exercise for all youth, irrespective of BMI status.

Conclusion

This large population-based study provides evidence for an association between muscular weakness in male adolescents and their risk of DP in mid-life. Moderate to high levels of muscular strength were associated with a lower risk of DP across different BMI categories. Muscular weakness was an especially important risk factor for DP when combined with low aerobic fitness. Moderate to high muscular strength and aerobic fitness jointly attenuated the increased risk of DP associated with obesity. It would be prudent to begin preventive actions at young ages and combine muscular strength and aerobic fitness enhancing exercise.

Acknowledgements

The authors thank Finn Rasmussen for contributing to study design, applying for ethics and feedback on early versions of the manuscript.

Contributors:

HH: responsible for data analyses and manuscript preparation, PH: responsible for data analysis and manuscript preparation, PT: contributed to data analyses and manuscript preparation, FBO: responsible for study design, contributed to data analysis and manuscript preparation.

Funding:

Hanna Henriksson was supported by a grant from The Swedish Society of Medicine and the County Council of Östergötland, Sweden. Pontus Henriksson was supported by grants from Henning and Johan Throne-Holst Foundation and the Strategic Research Area Health Care Science, Karolinska Institutet/Umeå University. Francisco B Ortega was supported by a visiting grant from Henning and Johan Throne-Holst Foundation. Additional support was obtained from the European Union's Horizon 2020 research and innovation programme under grant agreement No 667302; the University of Granada, Plan Propio de Investigación 2016, Excellence actions: Units of Excellence, Unit of Excellence on Exercise and Health (UCEES); the SAMID III network, RETICS, funded by the PN I+D+I 2017-2021 (Spain), ISCIII- Sub-Directorate General for Research Assessment and Promotion, the European Regional Development Fund (ERDF) (Ref. RD16/0022); and the EXERNET Research Network on Exercise and Health in Special Populations (DEP2005-00046/ACTI).

Competing interests:

None declared.

Ethical approval information:

The Regional Ethics committee, Stockholm, Sweden.

Data sharing statement:

We do not have ethical approval to share the data. However, the data is from Swedish national registers and can be obtained from the relevant authorities for researchers who have ethical permission.

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Table 1. Basic characteristics of the study sample (n = 1 212 503).

	Mean (SD)
Age at conscription	18.4 ± 0.5
Weight (kg)	69.6 ± 10.3
Height (cm)	179.2 ± 6.5
BMI at conscription (kg/m ²)	21.65 ± 2.82
Knee extension strength* (N)	569.7 ± 117.6
Handgrip strength [†] (N)	615.9 ± 97.6
Elbow flexion strength [‡] (N)	387.0 ± 84.1
Exercise capacity ^{§,} (W)	275.2 ± 52.0
	% (N)
BMI categories %	
Underweight (< 18.5 kg/m ²)	8.7 % (105 429)
Normal-weight (18.5-24.9 kg/m ²)	81.3 % (985 321)
Overweight (25.0-29.9 kg/m ²)	8.4 % (102 353)
Obesity class I (30.0-34.9 kg/m ²)	1.3 % (16 252)
Obesity class II (35.0-39.9 kg/m ²)	0.2 % (2 731)
Obesity class III (≥ 40.0 kg/m ²)	0.03 % (417)
Highest parental occupation %	
Non-manual workers at higher level	8.4 % (101 307)
Non-manual workers at intermediate level	20.5 % (248 903)
Non-manual workers at lower level	15.3 % (185 558)
Self-employed or farmers	8.2 % (99 036)
Skilled workers	33.5 % (406 375)
Unskilled workers	11.4 % (138190)
Others	2.7 % (33134)
Disability pension	
All causes	5.7 % (69 248)
Psychiatric	2.5 % (29 780)
Musculoskeletal	1.4 % (16 914)
Injuries	0.5 % (6 478)
Nervous system	0.3 % (4 179)
Circulatory	0.3 % (3 743)
Tumors	0.1 % (1 358)
Other causes	0.6 % (6 896)

BMI, body mass index.

* Quintile 1 ≤ 470 N (n=251 111); Quintile 2 = 471-530 N (n=237 488); Quintile 3 = 531-590 N (n=246 887); Quintile 4 = 591-660 N (n=237 327); Quintile 5 ≥ 661 N (n=239 690).

[†] Quintile 1 ≤ 539 N (n=240 103); Quintile 2 = 540-589 N (n=227 891); Quintile 3 = 590-639 N (n=258 398); Quintile 4 = 640-699 N (n=243 120); Quintile 5 ≥ 700 N (n=242 991).

[‡] Quintile 1 ≤ 319 N (n=239 864); Quintile 2 = 320-359 N (n=228 743); Quintile 3 = 360-399 N (n=232 487); Quintile 4 = 400-450 N (n=280 265); Quintile 5 ≥ 451 N (n=231 144).

[§] Quintile 1 ≤ 229 W (n=223 721); Quintile 2 = 230-254 W (n=206 397); Quintile 3 = 255-284 W (n=218 669); Quintile 4 = 285-320 W (n=215 363); Quintile 5 ≥ 321 W (n=214 427).

^{||} n = 1 078 577

Figure legends

Figure 1. Associations of different measures of muscular strength with all-cause disability pension (DP) (n = 1 212 503). Basic adjustments in the analyses were: childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Figure 2. Associations of knee extension muscular strength with specific causes of disability pension (DP) (n = 1 212 503). Basic adjustments in the analyses were: childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Figure 3. Associations of knee extension muscle strength with disability pension (DP) due to all-cause, psychiatric and musculoskeletal causes throughout BMI categories (n = 1 212 503). BMI was classified as UW (underweight: $< 18.5 \text{ kg/m}^2$), NW (normal-weight: $18.5\text{-}24.9 \text{ kg/m}^2$), OW (overweight: $25.0\text{-}29.9 \text{ kg/m}^2$), OB 1 (obesity class I: $30.0\text{-}34.9 \text{ kg/m}^2$) and OB 2-3 (obesity class II: $35.0\text{-}39.9 \text{ kg/m}^2$; obesity class III: $\geq 40.0 \text{ kg/m}^2$). Adolescents in strength quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Figure 4. Associations of the combination of knee extension muscle strength and aerobic fitness with disability pension (DP) due to all-cause, psychiatric and musculoskeletal causes (n = 1 078 577). Adolescents in quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center, conscription year and BMI. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Figure 5. Associations of the combination of knee extension muscle strength and aerobic fitness with all-cause disability pension (DP) for normal weight (n = 878 967) and obese class 1-3 individuals (n = 17 912). Adolescents in quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Supplementary table 1. International Classification of Diseases (ICD codes) used in the study.

	ICD-10	ICD-9	ICD-8
Circulatory	Chapter I	390-398, 401-405, 410-417, 420-438, 440-448, 451-459	390-392, 400-404, 410- 414, 420-429, 430-438, 440-448, 450-458
Psychiatric	Chapter F	290-319	290-315
Musculoskeletal	Chapter M	710-739	710-718, 720-738
Nervous system	Chapter G	320-326, 330-337, 340-359	320-324, 330-358
Tumours	Chapter C, D 00-48	140-165, 170-176, 179-208, 210-239	140-163, 170-174, 180- 228, 230-239
Injuries	Chapter S, T, V, W, X, Y	800-848, 850-854, 860-887, 890-897, 900-999 Chapter E	Chapter E, N
Others	If not any of the others	If not any of the others	If not any of the others

Supplementary table 2. Associations of knee extension, handgrip and elbow flexion muscular strength with disability pension due to all causes (n = 1 212 503). Basic adjustments in the analyses were: childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Strength measure	Strength quintile	Basic adjustment HR (95 % CI)	Basic adjustment + BMI HR (95 % CI)
Knee extension	1	1.25 (1.22, 1.28)	1.40 (1.36, 1.44)
	2	1.11 (1.08, 1.14)	1.20 (1.17, 1.24)
	3	1.06 (1.03, 1.08)	1.12 (1.10, 1.16)
	4	1.01 (0.98, 1.03)	1.05 (1.02, 1.08)
	5	Reference	Reference
Handgrip	1	1.15 (1.13, 1.18)	1.22 (1.19, 1.25)
	2	1.00 (0.98, 1.03)	1.05 (1.02, 1.07)
	3	0.96 (0.94, 0.98)	0.99 (0.97, 1.01)
	4	0.95 (0.93, 0.97)	0.97 (0.95, 0.99)
	5	Reference	Reference
Elbow flexion	1	1.00 (0.98, 1.03)	1.09 (1.06, 1.12)
	2	0.92 (0.90, 0.95)	0.98 (0.96, 1.01)
	3	0.92 (0.89, 0.94)	0.96 (0.94, 0.98)
	4	0.92 (0.90, 0.94)	0.94 (0.92, 0.97)
	5	Reference	Reference

CI, confidence interval; HR, hazard ratio.

Supplementary table 3. Associations of **handgrip strength** muscular strength with disability pension (n = 1 212 503). Basic adjustments in the analyses were: childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Disability cause	Strength quintile	Basic adjustment HR (95 % CI)	Basic adjustment + BMI HR (95 % CI)
<i>Psychiatric</i>	1	1.62 (1.56, 1.67)	1.57 (1.52, 1.63)
	2	1.25 (1.20, 1.30)	1.22 (1.18, 1.27)
	3	1.12 (1.08, 1.17)	1.11 (1.06, 1.15)
	4	1.05 (1.01, 1.10)	1.04 (1.00, 1.09)
	5	Reference	Reference
<i>Musculoskeletal</i>	1	0.74 (0.71, 0.78)	0.83 (0.79, 0.88)
	2	0.78 (0.74, 0.81)	0.85 (0.81, 0.89)
	3	0.78 (0.75, 0.82)	0.83 (0.79, 0.87)
	4	0.84 (0.81, 0.88)	0.88 (0.84, 0.92)
	5	Reference	Reference
<i>Injuries</i>	1	0.85 (0.79, 0.92)	0.90 (0.83, 0.97)
	2	0.87 (0.81, 0.94)	0.91 (0.84, 0.98)
	3	0.89 (0.82, 0.96)	0.92 (0.85, 0.99)
	4	0.89 (0.83, 0.96)	0.91 (0.84, 0.98)
	5	Reference	Reference
<i>Nervous system</i>	1	1.39 (1.27, 1.53)	1.45 (1.31, 1.59)
	2	1.06 (0.96, 1.17)	1.09 (0.99, 1.21)
	3	1.07 (0.97, 1.18)	1.09 (0.99, 1.20)
	4	0.96 (0.87, 1.06)	0.97 (0.88, 1.07)
	5	Reference	Reference
<i>Circulatory</i>	1	1.02 (0.93, 1.13)	1.25 (1.13, 1.38)
	2	1.00 (0.91, 1.11)	1.16 (1.05, 1.29)
	3	0.92 (0.83, 1.01)	1.02 (0.92, 1.13)
	4	0.89 (0.81, 0.99)	0.96 (0.87, 1.06)
	5	Reference	Reference
<i>Tumours</i>	1	1.04 (0.88, 1.23)	1.10 (0.93, 1.31)
	2	0.83 (0.69, 0.99)	0.87 (0.72, 1.04)
	3	0.97 (0.82, 1.14)	1.00 (0.85, 1.18)
	4	1.04 (0.88, 1.23)	1.06 (0.90, 1.25)
	5	Reference	Reference
<i>Other</i>	1	1.32 (1.23, 1.42)	1.57 (1.46, 1.70)
	2	1.11 (1.03, 1.20)	1.27 (1.17, 1.37)
	3	1.06 (0.98, 1.14)	1.16 (1.08, 1.26)
	4	1.04 (0.96, 1.13)	1.11 (1.03, 1.20)
	5	Reference	Reference

CI, confidence interval; HR, hazard ratio.

Supplementary table 4. Associations of **knee extension** muscular strength with disability pension (n = 1 212 503). Basic adjustments in the analyses were: childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Disability cause	Strength quintile	Basic adjustment HR (95 % CI)	Basic adjustment + BMI HR (95 % CI)
<i>Psychiatric</i>	1	1.51 (1.46, 1.57)	1.47 (1.41, 1.53)
	2	1.29 (1.24, 1.34)	1.26 (1.21, 1.31)
	3	1.15 (1.11, 1.20)	1.14 (1.09, 1.18)
	4	1.06 (1.02, 1.10)	1.05 (1.01, 1.09)
	5	Reference	Reference
<i>Musculoskeletal</i>	1	1.04 (0.99, 1.10)	1.32 (1.25, 1.39)
	2	0.97 (0.92, 1.02)	1.15 (1.09, 1.21)
	3	0.97 (0.92, 1.02)	1.10 (1.04, 1.16)
	4	0.95 (0.90, 1.00)	1.03 (0.98, 1.09)
	5	Reference	Reference
<i>Injuries</i>	1	0.99 (0.92-1.08)	1.11 (1.02, 1.20)
	2	0.99 (0.91-1.07)	1.07 (0.98, 1.16)
	3	0.95 (0.87, 1.03)	1.00 (0.92, 1.09)
	4	0.94 (0.87, 1.02)	0.98 (0.90, 1.06)
	5	Reference	Reference
<i>Nervous system</i>	1	1.54 (1.39, 1.70)	1.68 (1.51, 1.88)
	2	1.20 (1.07, 1.33)	1.28 (1.14, 1.43)
	3	1.16 (1.04, 1.29)	1.22 (1.09, 1.36)
	4	1.14 (1.02, 1.28)	1.18 (1.05, 1.32)
	5	Reference	Reference
<i>Circulatory</i>	1	1.04 (0.94, 1.16)	1.47 (1.31, 1.64)
	2	0.91 (0.81, 1.01)	1.16 (1.04, 1.31)
	3	0.99 (0.89, 1.11)	1.20 (1.07, 1.34)
	4	0.95 (0.85, 1.07)	1.07 (0.95, 1.21)
	5	Reference	Reference
<i>Tumours</i>	1	1.01 (0.85, 1.19)	1.11 (0.93, 1.34)
	2	0.89 (0.74, 1.06)	0.96 (0.79, 1.15)
	3	0.87 (0.72, 1.04)	0.92 (0.76, 1.10)
	4	0.94 (0.78, 1.13)	0.97 (0.81, 1.17)
	5	Reference	Reference
<i>Other</i>	1	1.38 (1.27, 1.49)	1.90 (1.75, 2.06)
	2	1.09 (1.00, 1.18)	1.38 (1.26, 1.50)
	3	1.05 (0.96, 1.14)	1.25 (1.15, 1.36)
	4	0.94 (0.86, 1.03)	1.06 (0.97, 1.16)
	5	Reference	Reference

CI, confidence interval; HR, hazard ratio.

Supplementary table 5. Associations of knee extension muscle strength with disability pension (DP) due to all-cause, psychiatric and musculoskeletal causes throughout BMI categories (n = 1 212 503). Adolescents in quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Disability cause	Weight status category	Strong (i.e. quintiles 2-5) HR (95 % CI)	Weak (quintile 1) HR (95 % CI)
<i>All-cause</i>	OB II-III	2.77 (2.49, 3.08)	3.62 (2.67, 4.89)
	OB I	1.71 (1.62, 1.81)	2.21 (1.87, 2.61)
	OW	1.29 (1.25, 1.32)	1.74 (1.62, 1.86)
	NW	Reference	1.19 (1.17, 1.22)
	UW	1.14 (1.10, 1.19)	1.33 (1.29, 1.36)
<i>Psychiatric</i>	OB II-III	1.93 (1.60, 2.31)	2.32 (1.35, 4.00)
	OB I	1.16 (1.04, 1.28)	1.60 (1.19, 2.14)
	OW	1.06 (1.01, 1.11)	1.54 (1.38, 1.73)
	NW	Reference	1.29 (1.25, 1.32)
	UW	1.35 (1.28, 1.42)	1.60 (1.53, 1.67)
<i>Musculoskeletal</i>	OB II-III	3.44 (2.80, 4.23)	4.05 (2.18, 7.53)
	OB I	2.21 (1.98, 2.45)	2.31 (1.63, 3.26)
	OW	1.50 (1.43, 1.58)	2.05 (1.81, 2.33)
	NW	Reference	1.13 (1.08, 1.17)
	UW	0.95 (0.87, 1.03)	1.07 (1.00, 1.14)

CI, confidence interval; HR, hazard ratio.

Supplementary table 6. Associations of the combination of knee extension muscle strength and aerobic fitness with disability pension (DP) due to all-cause, psychiatric and musculoskeletal causes (n = 1 078 577). Adolescents in quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center, conscription year and BMI. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

Disability cause	Combination of strength and aerobic fitness	HR (95% CI)
<i>All-cause</i>	Unfit and weak	1.80 (1.75, 1.84)
	Unfit and strong	1.62 (1.58, 1.65)
	Fit and weak	1.25 (1.22, 1.29)
	Fit and strong	Reference
<i>Psychiatric</i>	Unfit and weak	1.90 (1.82, 1.97)
	Unfit and strong	1.69 (1.63, 1.75)
	Fit and weak	1.30 (1.25, 1.35)
	Fit and strong	Reference
<i>Musculoskeletal</i>	Unfit and weak	1.80 (1.70, 1.90)
	Unfit and strong	1.63 (1.55, 1.70)
	Fit and weak	1.19 (1.12, 1.26)
	Fit and strong	Reference

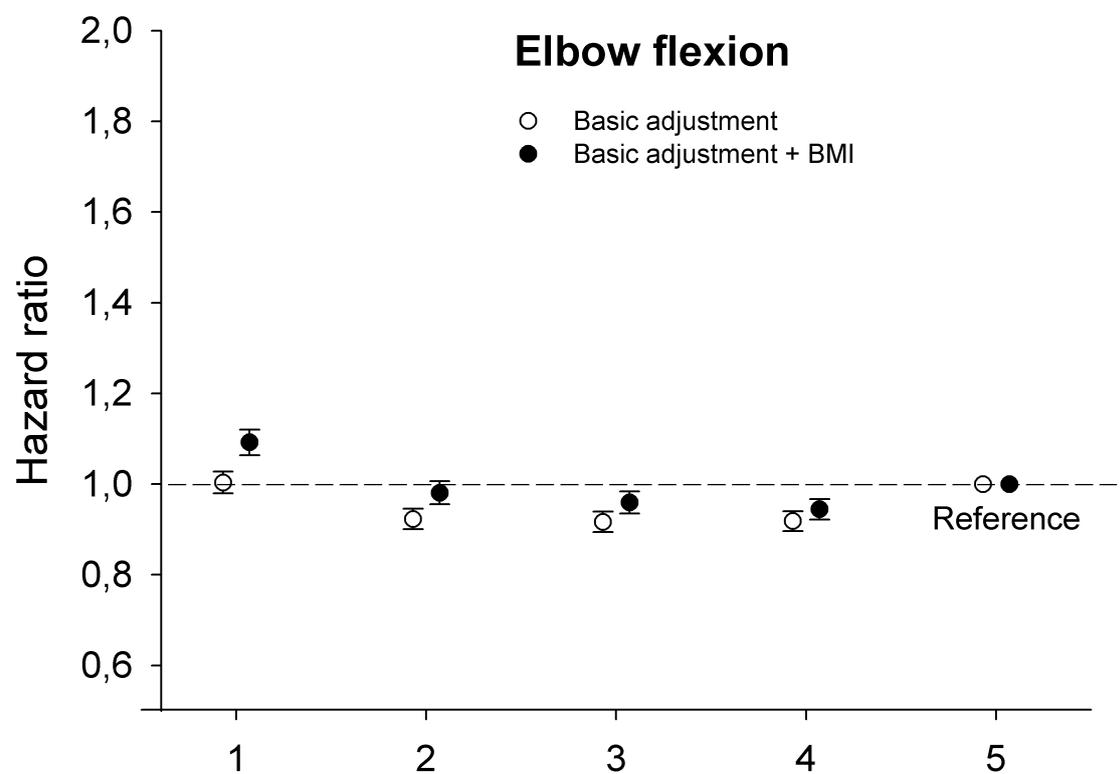
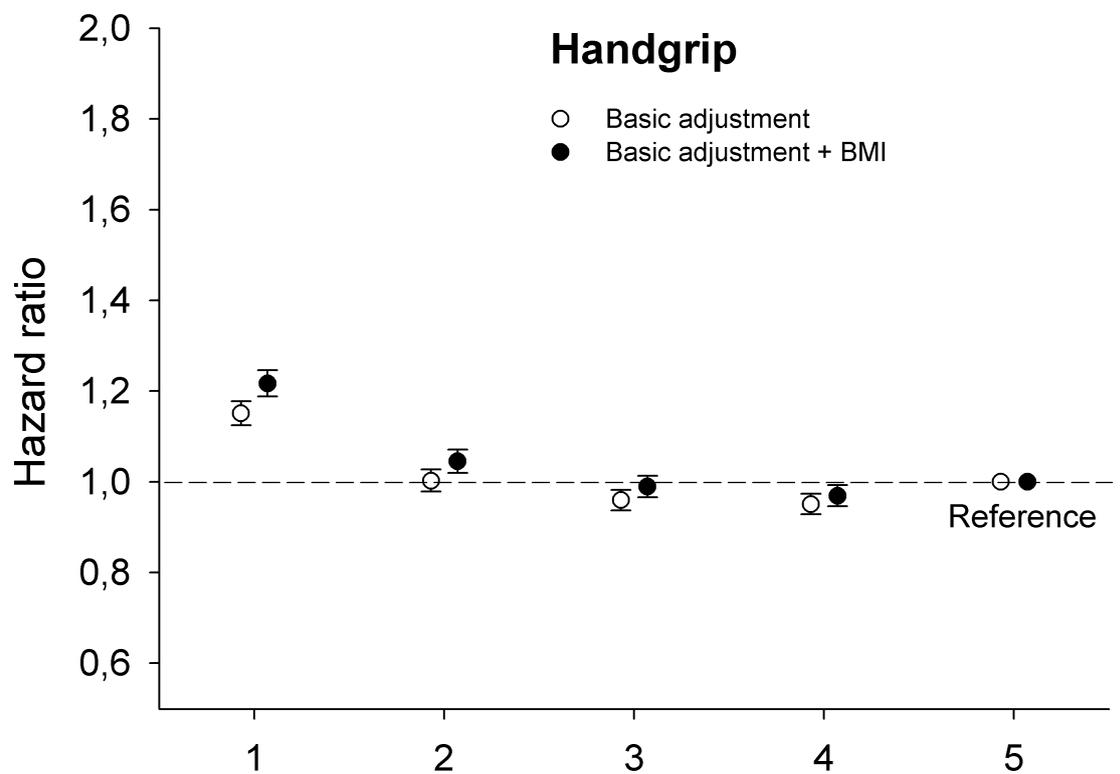
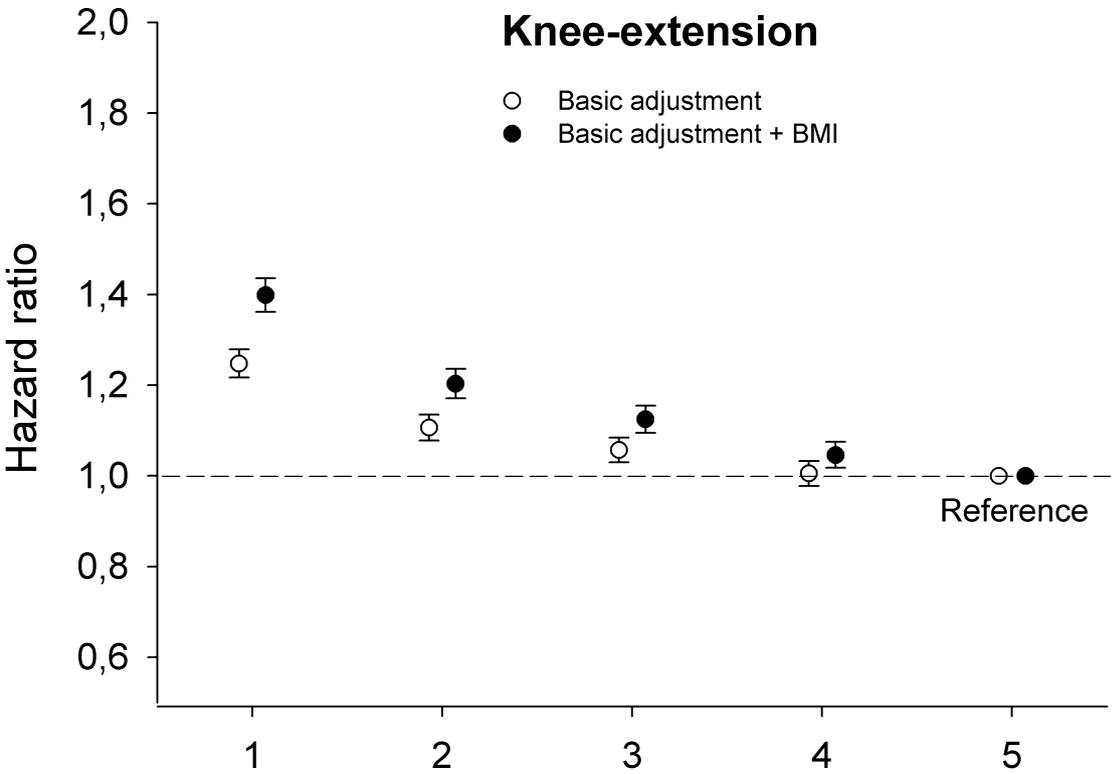
CI, confidence interval; HR, hazard ratio.

Supplementary table 7. Associations of the combination of knee extension muscle strength and aerobic fitness with all-cause disability pension (DP) for underweight (n = 94 184), normal weight (n = 878 967), overweight (n = 87 514) and obese individuals (n = 17 912). Adolescents in quintile 1 were considered as “weak” while adolescents in quintiles 2 to 5 were considered “strong”. Analyses were adjusted for childhood socioeconomic status, age at conscription, conscription center and conscription year. All analyses with DP due to all and psychiatric causes were additionally adjusted for any mental hospitalization before conscription and for any psychiatric diagnosis at conscription.

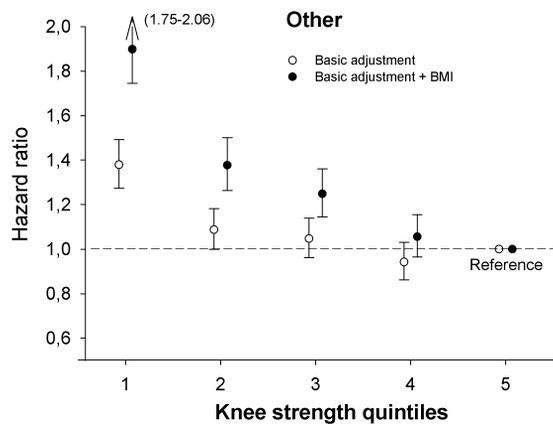
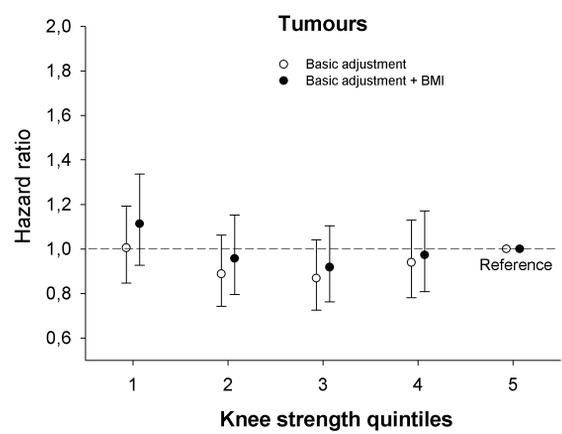
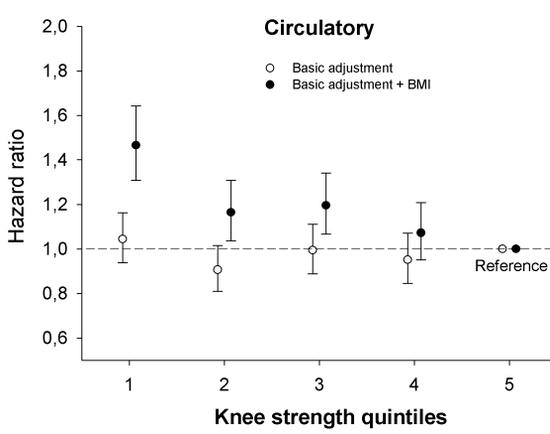
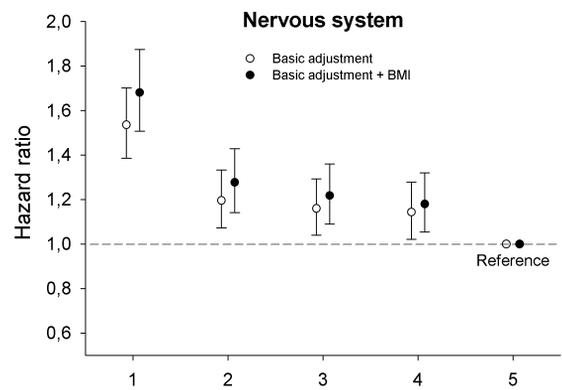
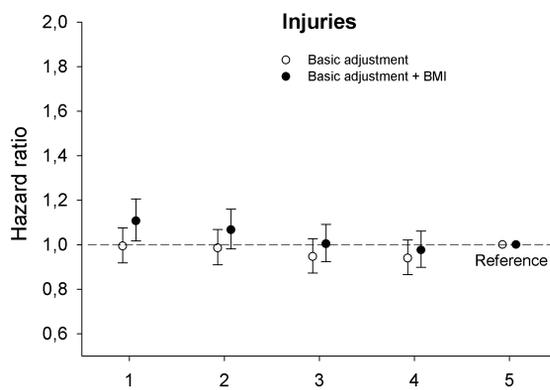
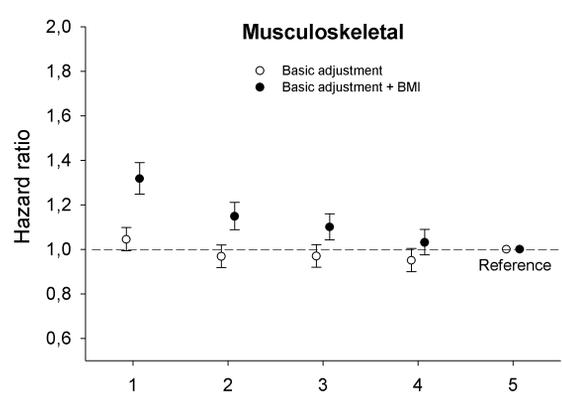
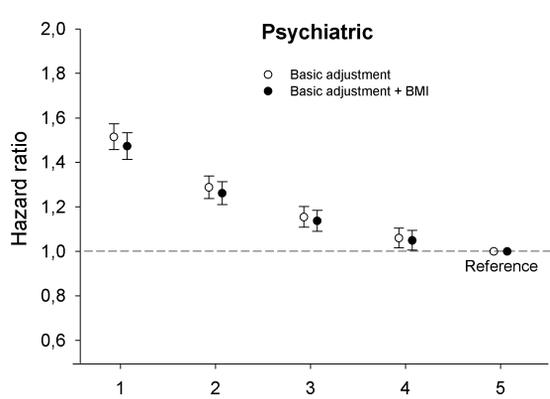
Weight status category	Combination of strength and aerobic fitness	HR (95% CI)
Obese I-III	Unfit and weak	3.70 (2.99, 4.58)
Obese I-III	Unfit and strong	2.70 (2.43, 3.01)
Obese I-III	Fit and weak	2.17 (1.70, 2.75)
Obese I-III	Fit and strong	1.92 (1.80, 2.05)
Overweight	Unfit and weak	2.43 (2.17, 2.72)
Overweight	Unfit and strong	2.03 (1.91, 2.17)
Overweight	Fit and weak	1.76 (1.59, 1.96)
Overweight	Fit and strong	1.33 (1.28, 1.37)
Normal weight	Unfit and weak	1.67 (1.62, 1.72)
Normal weight	Unfit and strong	1.59 (1.55, 1.63)
Normal weight	Fit and weak	1.20 (1.16, 1.24)
Normal weight	Fit and strong	Reference
Underweight	Unfit and weak	1.72 (1.66, 1.80)
Underweight	Unfit and strong	1.53 (1.44, 1.62)
Underweight	Fit and weak	1.33 (1.24, 1.42)
Underweight	Fit and strong	1.12 (1.05, 1.20)

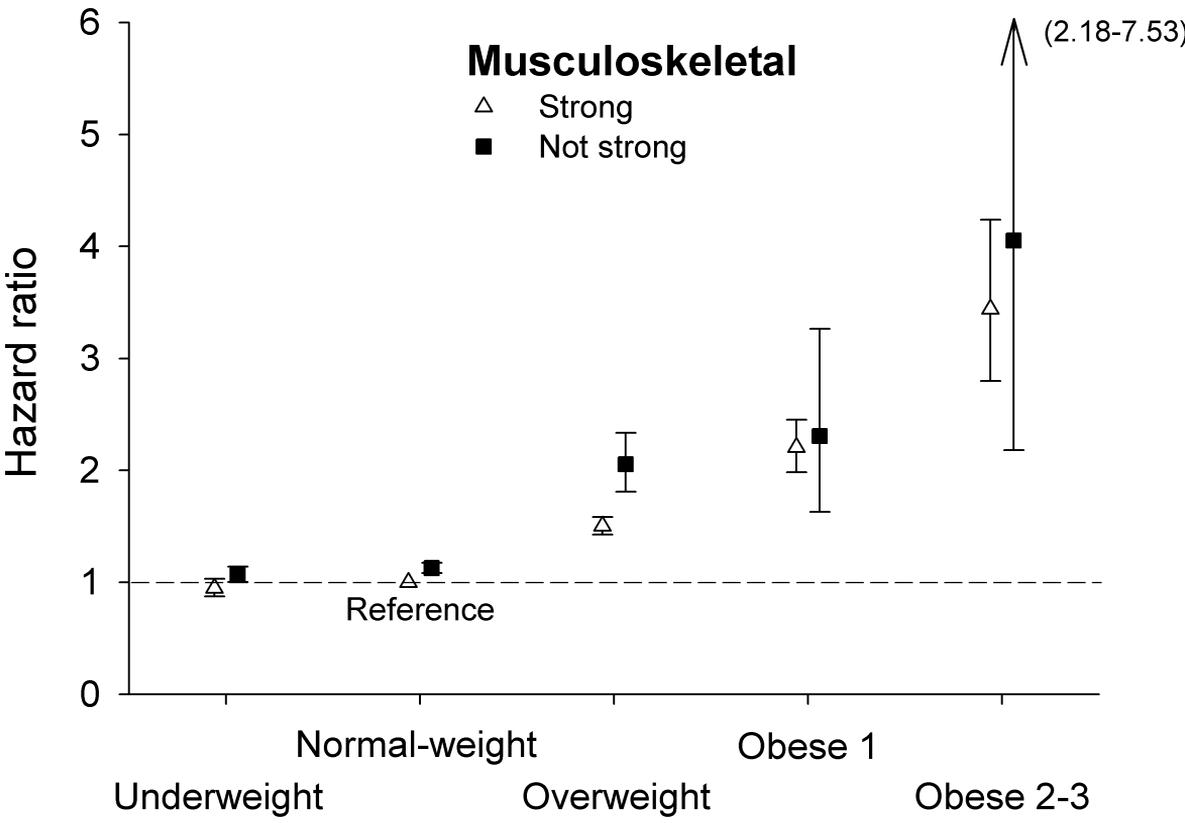
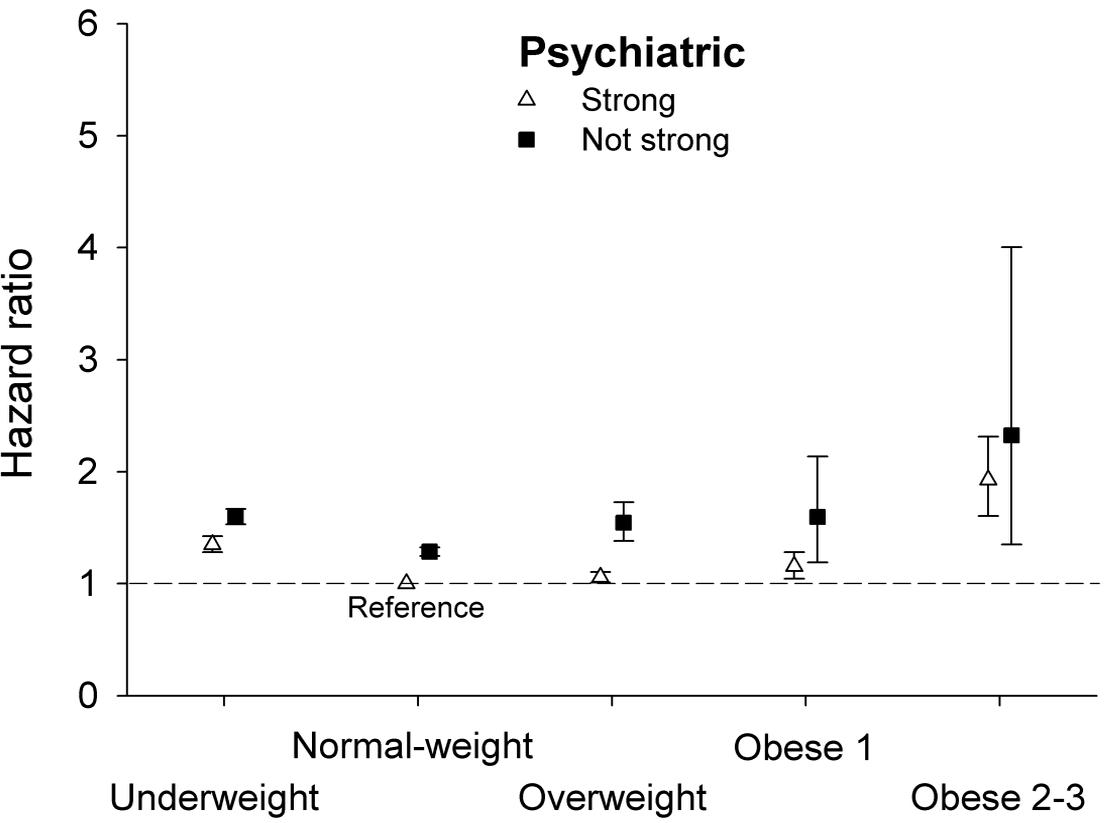
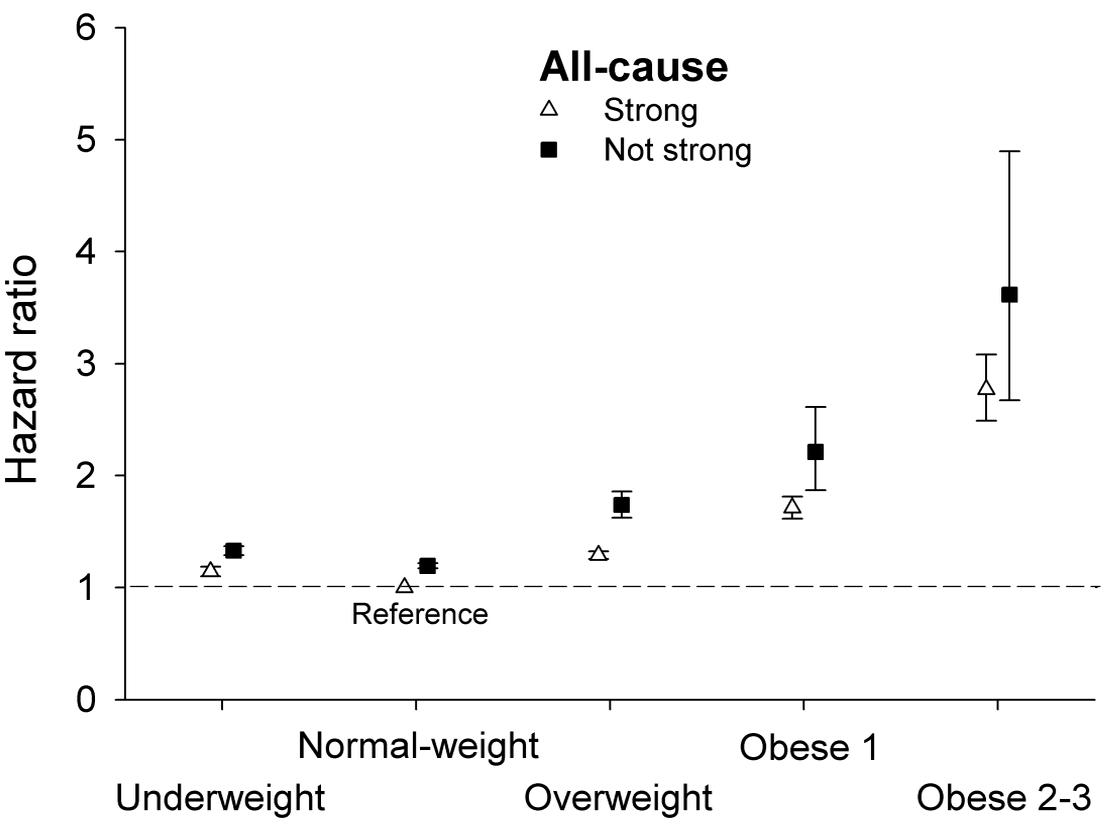
CI, confidence interval; HR, hazard ratio.

All-cause disability pension

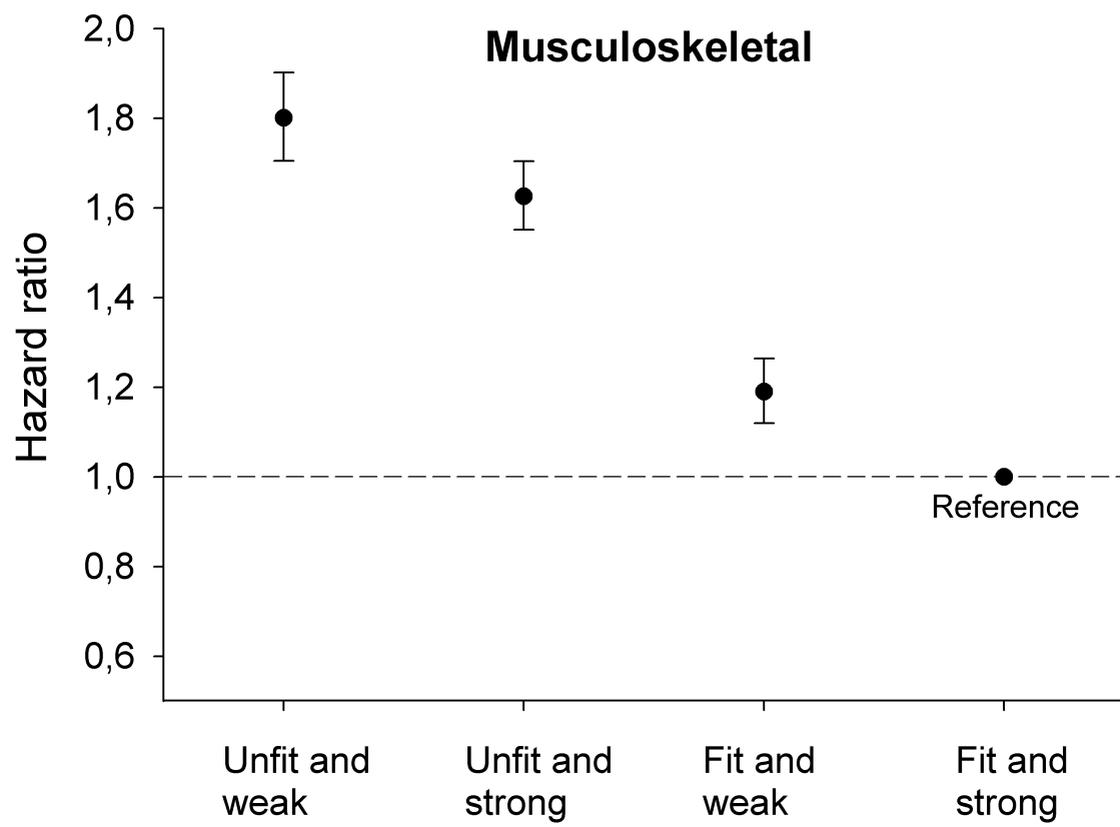
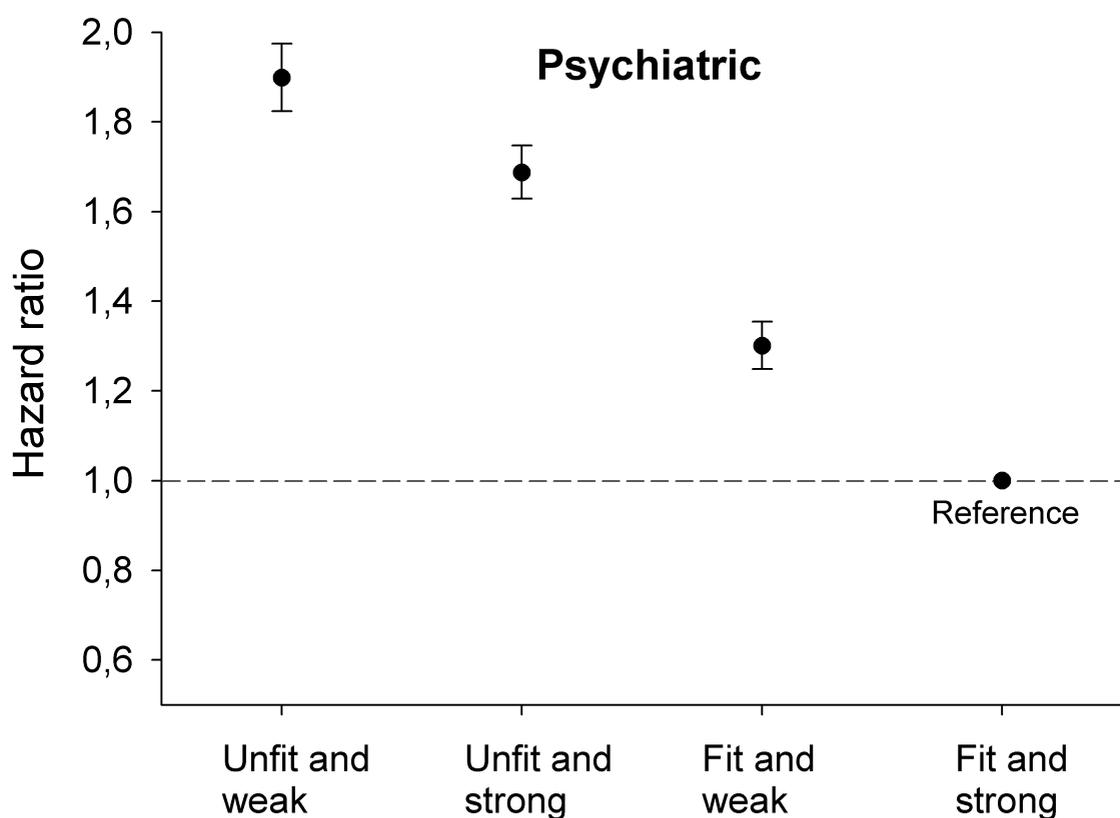
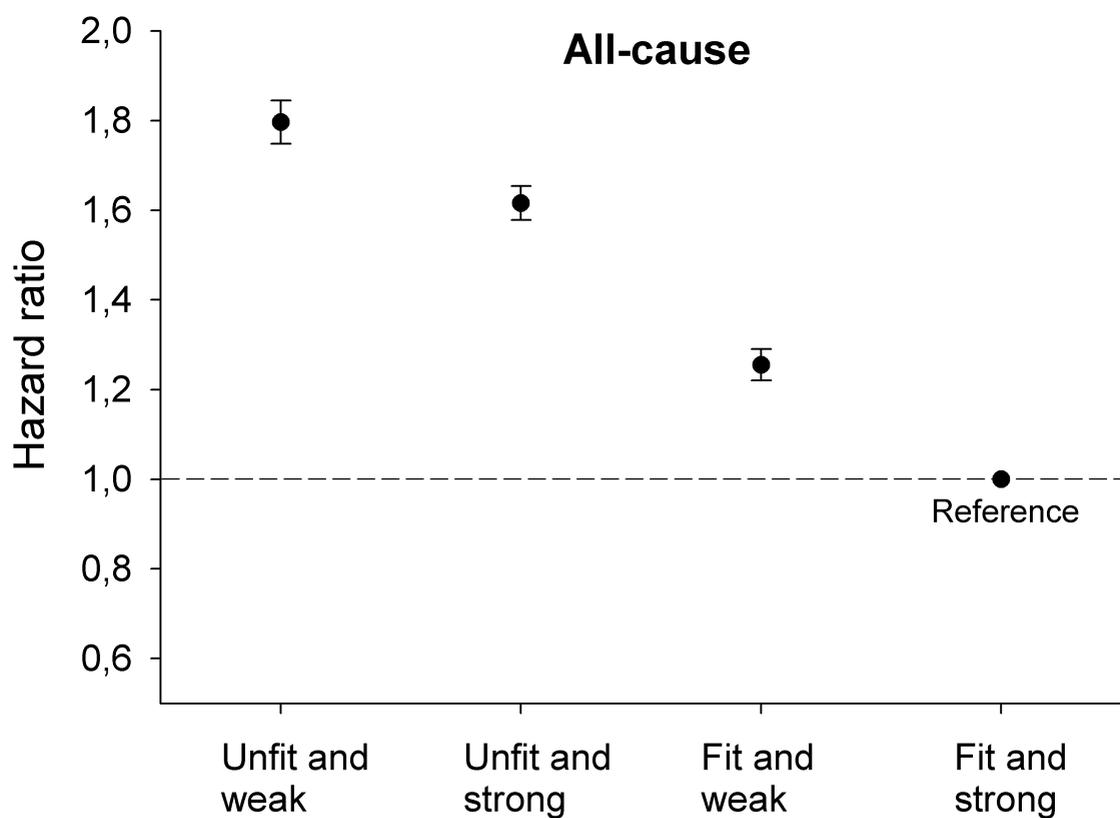


Strength quintiles





Weight status categories



All-cause

