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Thorsten Klein

thorsten.klein@ph-karlsruhe.de

Karlsruhe University of Education

Anke Hanssen-Doose

Karlsruhe University of Education

Leon Klos

Karlsruhe Institute of Technology

Augustin Kelava

University of Tübingen

Samuel Merk

Karlsruhe University of Education

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Sex, anthropometric, behavioural, and
socioeconomic disparities in physical strength of
german children and adolescents

Thorsten Klein^{1*}, Anke Hanssen-Doose¹, Leon Klos²,
Augustin Kelava³, Samuel Merk⁴

¹Institute of Movement and Sport, Karlsruhe University of Education,
Bismarckstraße 10, Karlsruhe, 76133, Baden-Württemberg, Germany.

²Institute of Sports and Sports Science, Karlsruhe Institute of
Technology, Engler-Bunte-Ring 15, Karlsruhe, 76131,
Baden-Württemberg, Germany.

³Methods Center, University of Tübingen, Haufferstraße 11, Tübingen,
72076, Baden-Württemberg, Germany.

⁴Department of school and teaching development, Karlsruhe University
of Education, Bismarckstraße 10, Karlsruhe, 76133,
Baden-Württemberg, Germany.

*Corresponding author(s). E-mail(s): thorsten.klein@ph-karlsruhe.de;
Contributing authors: anke.hanssen-doose@ph-karlsruhe.de;
leon.klos@kit.edu; augustin.kelava@uni-tuebingen.de;
samuel.merk@ph-karlsruhe.de;

Abstract

Background: Evidence suggests that sex, body composition, physical activity (PA), and socioeconomic status (SES) significantly influence development of physical strength - a key factor for health - in youth. However most research has focused on isolated age groups or regions, limiting broader generalizability. This study aims to investigate sex, anthropometric, behavioral, and socioeconomic disparities in physical strength using representative data from Germany. **Methods:** We analysed a combination of cross-sectional and longitudinal data from 13,735

individuals (aged 4–31 years) assessed in three waves of the Motorik-Modul (MoMo) study (2003-2017). Physical strength was measured using standing long jump, sit-ups, and push-ups. Body fat percentage (BF%) was measured via bioelectrical impedance analysis and age, sex, SES, and PA were self-reported. A latent strength variable was calculated through confirmatory factor analysis based on the three strength tasks. Using Generalized Additive Models for Location and Scale with the Gaussian location-scale model family (GAMLSS) disparities based on sex, BF%, PA, and SES were estimated. Marginal effects (Cohen’s d for sex and Pearson’s r for BF%, PA, and SES) were calculated for the ages 10 and 18. **Results:** GAMLSS explained up to 74.6% of variance in strength-related measures. Sex disparities in physical strength emerged around puberty, with males showing performance increases while females stagnated or declined. By age 18, effect sizes ranged from $d=.92$ (push-ups and sit-ups) to $d=2.22$ (standing long jump), highlighting a widening performance gap. BF% had a strong effect, with performance differences widening by late adolescence. At age 18, marginal effects ranged from $r=-.45$ (sit-ups) to $r=-.91$ (standing long jump). PA disparities in physical strength increased with age as well, with marginal effects ranging from $r=.31$ (sit-ups) to $r=.36$ (push-ups) at age 18. SES had a minor impact, though higher SES was linked to slightly better performance, particularly after puberty. Marginal effects for SES at age 18 ranged from $r=.11$ (pus-ups and sit-ups) to $r=.17$ (standing long jump). **Conclusion:** Our findings highlight the importance of addressing sex, anthropometric, and behavioral disparities in youth strength development, especially during puberty. Future research should explore nutritional and psychological factors, alongside detailed body composition and physical activity intensity measures.

Keywords: Strength, Disparities, Children and Adolescents, Muscular fitness

1 Introduction

Physical fitness is a crucial indicator of health, with significant implications for present and future well-being [1, 2]. Research has shown that higher physical fitness during childhood and adolescence are associated with a reduced risk of current and future diseases [3, 4]. Notably, factors like obesity, low socioeconomic status, and sedentary lifestyles are linked to decreased physical fitness in young populations [5–7]. A widely adopted model in Germany defines four primary physical fitness dimensions: endurance, strength, speed, and coordination, with flexibility considered an additional passive energy transfer system [8, 9]. This model is particularly applicable for assessing physical fitness in children and adolescents [9]. Furthermore, the primary dimensions

can be subdivided. Strength, for instance, comprises muscular endurance, maximum strength, and speed strength [9]. Internationally, the term muscular fitness - closely aligned with strength as defined by Bös et al. (1987) [8] - is increasingly used. This concept combines the fitness components of muscular strength, muscular endurance, and muscular power [10], forming the integrated measure of muscular fitness [11, 12].

Alongside cardiorespiratory fitness, muscular fitness is recognised as a key determinant of current health and future disease risk [12–14]. Higher muscular fitness in youth is associated with improved physical health (e.g., lower adiposity, better cardiovascular and bone health [1, 12]) and psychological health (e.g., enhanced self-perception, higher self-esteem [1, 12], and better self-rated health [15]). Reflecting this growing emphasis, muscle-strengthening activities have become integral to many institutional exercise recommendations aimed at maintaining and enhancing overall health [16]. While research has begun to explore disparities in strength development, most studies have focused on isolated age groups, often with limited sample sizes or regional data. The majority of work centers on sex-based differences - particularly the male advantage in upper-body strength - which emerges during puberty and intensifies thereafter [17, 18]. Behavioural and anthropometric factors, like physical activity (PA) and body composition, further contribute to diverging strength trajectories [19–24]. For example, while increased fat mass can impair strength in weight-bearing tasks, it may simultaneously enhance grip strength [22]. Socioeconomic disparities have also been documented, with lower-income youth - particularly girls - exhibiting reduced strength [20, 21, 25].

However, despite the growing body of evidence, no study to date has examined physical strength disparities from childhood through adolescence into young adulthood. This represents a gap in our understanding of how strength development is

shaped across different stages of growth, social backgrounds, and behavioral contexts. To address this gap, the present study investigates sex, anthropometric, behavioral, and socioeconomic disparities in physical strength. By capturing a broad developmental window and incorporating multiple influencing factors, we aim to provide new insights into strength development, thereby facilitating the identification of early interventions and targeted public health strategies.

2 Methods

2.1 Study sample

This study uses cross-sectional and longitudinal data from the Motorik-Modul (MoMo) study, assessing physical fitness and PA among children and adolescents aged 4-17 years in Germany [26, 27]. The MoMo study is part of the representative German Health Interview and Examination Survey for Children and Adolescents (KiGGS) [28], the first comprehensive health monitoring system for youth in Germany, led by the Robert Koch Institute. Initiated in 2003, KiGGS included MoMo as one of five substudies, with participants randomly chosen from population registries in 167 cities and municipalities in Germany [28, 29].

The MoMo study began its baseline data collection between 2003 and 2006 (T1), followed by three waves: Wave 1 (T2: 2009–2012), Wave 2 (T3: 2014–2017), and Wave 3 (T4: 2018–2022). At each wave, a representative cross-sectional-cohort aged 4-17 years was drawn. Participants from T1 were followed up longitudinally, combining with cross-sectional cohorts in a cohort-sequence design [2, 26]. Participants and their families were individually invited to nearby study centers, where trained test instructors conducted physical fitness assessments and surveys. Study centers were selected

to ensure accessibility, reducing travel for participants. This article combines cross-sectional and longitudinal data from T1 to T3. As a result, data from 13,735 individuals were analysed (Table 1).

Table 1: Descriptive statistics for the study sample

Variables	T1	T2	T3
Participants [N]	4528	5104	6233
Sex (m/f) [%]	50.5/49.5	49.2/50.8	48.2/51.8
Mean age ($\pm$ SD) [years]	10.0 (4.0)	13.0 (5.1)	14.4 (5.5)
Minimum age [years]	4.00	4.1	4.2
Maximum age [years]	18.0	26.0	31.7
Standing long jump [N]	4501	3770	4488
Standing long jump mean ($\pm$ SD) [cm]	133.3 (38.6)	149.9 (38.8)	154.5 (38.1)
Push-ups [N]	3523	3394	4187
Push-ups mean ($\pm$ SD) [reps]	11.6 (3.9)	13.2 (4.1)	13.5 (4.1)
Sit-ups [N]	-	3405	4215
Sit-ups mean ($\pm$ SD) [reps]	-	20.5 (6.8)	19.9 (6.2)
Body fat percentage [N]	4454	3596	3828
Body fat percentage mean ($\pm$ SD) [%]	19.5 (7.9)	21.1 (7.1)	21.6 (7.9)
Physical activity [N]	4528	5104	6233
Physical activity mean ($\pm$ SD) [min]	233.3 (188.3)	255.2 (196.9)	250.0 (202.7)
Socioeconomic status [N]	4495	4065	5043
Socioeconomic status mean ($\pm$ SD)	11.7 (3.8)	13.1 (3.4)	14.2 (3.9)

N = Number; m = Male; f = Female; SD = Standard deviation; cm = Centimeters; reps = Repetitions; min = Minutes

2.2 Strength measures

Physical fitness - based on the approach by Bös (1987) [8] – was assessed using the 12-item MoMo test profile [30, 31]. Physical strength was assessed using the following three test items: (1) Standing long jump: Maximum jumping performance from a standing position in cm (maximum from two valid trials). (2) Push-ups: Number of completed push-ups within 40 seconds (one trial). (3) Sit-ups: Number of completed sit-ups within 40 seconds (one trial).

231 It is important to note that the sit-up test was added during the second measure-
232 ment wave (T2) to optimise the MoMo test profile. Additionally, push-ups and sit-ups
233 were administered from the age of six onwards for developmental reasons, while the
234 other tests were administered from the age of four onwards.
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239 **2.3 Anthropometric measure**

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241 Body composition was assessed using tetrapolar bioelectrical impedance analysis
242 (BIA) to measure resistance (R) and reactance (Xc) between the right wrist and
243 ankle via surface electrodes, conducted with a body impedance analyser (BIA 2000-S;
244 Data Input, Frankfurt, Germany) [32]. Before measurements, individuals remained in
245 a quiet supine position for at least three minutes, after which R and Xc were recorded
246 over a 15-second interval until no further changes were observed between consecutive
247 measurements. The final recorded value was documented [32]. Total body fat (kg) was
248 calculated using formulas from the NutriPlus software package by Data Input [33].
249 The body fat percentage (BF%) was determined by dividing the total fat mass by
250 total body weight.
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259 **2.4 Behavioural measure**

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261 Self-reported PA was assessed using the MoMo Physical Activity Questionnaire
262 (MoMo-PAQ), which covers various types and contexts of PA as well as overall activ-
263 ity [34]. For younger children, parental or legal guardians' assistance was provided
264 during the questionnaire process under the supervision of a trained test instructor,
265 depending on the child's reading and writing skills. The total weekly duration of PA
266 during leisure time sports activities in and outside sports clubs, physical education in
267 kindergarten and school and in extracurricular sports activities was summed up to a
268 PA index.
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2.5 Socioeconomical measure	277
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Socioeconomic status (SES) was calculated based on the education and occupation of	279
both parents and the equivalized disposable household income. Each category of the	280
SES was scored between 1 and 7 using the highest score between parents. The scores	281
were summed to create a composite, multidimensional index ranging from 3 to 21 [35].	282
In the MoMo study, family SES was assessed until participants reached the age of 18.	283
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2.6 Statistical analyses	286
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To gain evidence for consistent measurement properties over time and across cohorts,	289
we applied longitudinal measurement invariance testing for the dependent variables	290
[36, 37], using a series of confirmatory factor analysis (CFA) models with increasing	291
equality constraints [38]. The first model included τ -congeneric measurement models	292
[39] assigning the same indicators (standing long jump attempt one, standing long	293
jump attempt two, sit-ups, push-ups) to the latent variables (physical strength) over	294
time (configural invariance [40]). The second model constrained the associations	295
between the indicators and the latent variable to be equal over time (weak invari-	296
ance). The final models additionally constrained intercepts (strong invariance) and	297
residual variances (strict invariance) over time. All measurement invariance models	298
freely estimated a residual covariance parameter for the two standing long jump	299
attempts. Missing values were handled using full information maximum likelihood	300
estimation [41]. Results were evaluated by comparing fit indices with the results of	301
simulation studies [42, 43] and the indices of the other models.	302
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Generalized Additive Models for Location and Scale with the Gaussian loca-	316
tion-scale model family (GAMLSS) [44, 45] were applied, using Bartlett factor scores	317
from these CFAs and their indicator variables as dependent variables, since physical	318
strength in children and adolescents is primarily age-dependent and this relationship	319
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is both nonlinear and heteroscedastic [46, 47]. The core idea of any generalised additive model is to describe the relationship between predictors and an outcome with smooth functions constructed as a weighted sum (of arbitrary length) of basis functions, e.g., cubic splines [48]. To account for dependencies in the data introduced by repeated measurements, we used random intercepts [49] and additionally tested for cohort effects by introducing smoothed interaction terms of age and year of birth [50, 51]. To further investigate temporal changes in disparities, we estimated marginal effect sizes (Cohen’s d for sex and Pearson’s r for BF%, PA, and SES) at ages 10 and 18 years, as strength disparities widen with puberty around age 11. All analyses were run using functions of the lavaan [52] and gam [53] packages in R (Version 4.5.1) [54].

3 Results

The configural invariance model had 18 degrees of freedom (df), and the comparison of the model-implied and the empirical variance-covariance structure resulted in a χ^2 value of 676.635, a Root Mean Square Error of Approximation (RMSEA) of 0.073, a Standardised Root Mean Square Residual (SRMR) of 0.076, a Tucker-Lewis Index (TLI) of 0.966, a Bayesian Information Criterion (BIC) of 230602.5, and an Akaike Information Criterion (AIC) of 230425.0. Comparing these indices to absolute benchmarks [42] with due caution, we interpret them as evidence for the stability of the one-dimensionality of the strength measure over time. The weak invariance model ($\chi^2 = 694.250$, $df = 20$, $RMSEA = 0.070$, $SRMR = 0.081$, $TLI = 0.969$, $BIC = 230602.4$, $AIC = 230438.6$), as well as the strong invariance model ($\chi^2 = 812.727$, $df = 23$, $RMSEA = 0.071$, $SRMR = 0.083$, $TLI = 0.968$, $BIC = 230694.4$, $AIC = 230551.1$), resulted in very similar fit indices, indicating that constraining indicator loadings and intercepts did not substantially affect the congruence between the theoretically implied and empirically observed data structure. Finally, the strict invariance model showed

even better values for RMSEA and TLI ($\chi^2 = 869.611$, $df = 27$, $RMSEA = 0.068$, $SRMR = 0.084$, $TLI = 0.971$, $BIC = 230716.0$, $AIC = 230600.0$), but again produced very similar fit indices, providing evidence for longitudinal measurement invariance. Thus, using a one-dimensional factor score for physical strength, alongside the three primary measures (standing long jump, push-ups, sit-ups), was justified.

Table 2: Comparison of the GAMLSS models and the explained variances

a-models	b-models	c-models	Explained variance	Additional explained variance
Standing long jump $\sim$ Age			67.8%	-
Standing long jump $\sim$ Age	+ Birth year		67.9%	0.1%
Standing long jump $\sim$ Age		+ Sex	73.1%	5.3%
Standing long jump $\sim$ Age		+ Body fat percentage	74.6%	6.8%
Standing long jump $\sim$ Age		+ Physical activity	69.2%	1.4%
Standing long jump $\sim$ Age		+ Socioeconomic status	67.8%	0.0%
Push-ups $\sim$ Age			19.1%	-
Push-ups $\sim$ Age	+ Birth year		20.4%	1.3%
Push-ups $\sim$ Age		+ Sex	25.6%	6.5%
Push-ups $\sim$ Age		+ Body fat percentage	27.9%	8.8%
Push-ups $\sim$ Age		+ Physical activity	25.0%	5.9%
Push-ups $\sim$ Age		+ Socioeconomic status	20.3%	1.2%
Sit-ups $\sim$ Age			18.0%	-
Sit-ups $\sim$ Age	+ Birth year		18.8%	0.8%
Sit-ups $\sim$ Age		+ Sex	25.7%	7.7%
Sit-ups $\sim$ Age		+ Body fat percentage	29.7%	11.7%
Sit-ups $\sim$ Age		+ Physical activity	23.6%	5.6%
Sit-ups $\sim$ Age		+ Socioeconomic status	19.3%	1.3%
Strength $\sim$ Age			54.5%	-
Strength $\sim$ Age	+ Birth year		55.2%	0.7%
Strength $\sim$ Age		+ Sex	60.5%	6.0%
Strength $\sim$ Age		+ Body fat percentage	65.0%	11.5%
Strength $\sim$ Age		+ Physical activity	57.7%	3.2%
Strength $\sim$ Age		+ Socioeconomic status	56.8%	2.3%

First we modelled disparities across all dependent variables (standing long jump, push-ups, sit-ups, and the strength factor score) using a GAMLSS model including only a smoother for age with 20 weighted cubic regression splines as basis functions and random intercepts (a-models in Table 2). These models explained between 18.0% (sit-ups) and 67.8% (standing long jump) of the variance and exhibited the expected

non-linearity and heteroscedasticity. Cohort effects were tested via smoothed interaction terms between age and year of birth (b-models in Table 2). Since they added less than 1.3% to the explained variance for all dependent variables, we did not add them to the following disparity models (c-models in Table 2). The additionally explained variance of sex was substantial, ranging from 5.3% (standing long jump) to 7.7% (sit-ups). As depicted in Figure 1 the sex disparity becomes more pronounced with the onset of puberty in males at ages 12–13. Males showed a further significant increase in their performance across the three strength tasks, whereas female performance stagnated or even declined. Performance for both sexes gradually declined around age 20. The effect sizes (Cohen’s d) at age 10 ranged from $d=.09$ (push-ups) to $d=.36$ (standing long jump) and at age 18 ranged from $d=.92$ (push-ups and sit-ups) to $d=2.22$ (standing long jump).

The investigated anthropometric disparities also increased with age (Figure 1). The highest BF% quartile consistently exhibited lower performance across the three strength tasks at all ages. These disparities were clearly age-dependent, with much larger gaps at age 18, where the marginal effects (Pearson’s r) ranged from $r=-.45$ (sit-ups) to $r=-.91$ (standing long jump), compared to age 10, where the marginal effects ranged from $r=-.29$ (push-ups) to $r=-.60$ (standing long jump). The additionally explained variance (Table 2) of BF% was considerable, ranging from 6.8% (standing long jump) to 11.7% (sit-ups).

For the PA disparities, an age-related increase was observed (Figure 1). Performance in the three strength tasks improved with higher PA, and the differences between quartiles continued increasing with age. The marginal effects at age 10 were $r=.25$ for all strength measures and increased at age 18, where the marginal effects

ranged from $r=-.31$ (sit-ups) to $r=-.36$ (push-ups). The additionally explained variance of PA (Table 2) ranged from 1.4% (standing long jump) to 5.9% (push-ups).

SES showed significantly smaller disparities with less interaction with age (Figure 1). Nonetheless, a trend was observed where the highest SES quartile performed slightly better in the three strength tasks than the lowest SES quartile, especially with the onset of puberty. The additionally explained variance of SES (Table 2) ranged only from 0.0% (standing long jump) to 1.3% (push-ups). The marginal effects ranged from $r=.07$ (sit-ups) to $r=.09$ (standing long jump) at age 10 and from $r=.11$ (push-ups and sit-ups) to $r=.17$ (standing long jump) at age 18.

4 Discussion

Our analysis revealed clear patterns of disparities across demographic and physiological factors. The sex disparities observed align with existing literature, indicating that only males experience significant strength gains post-puberty [17, 18]. This was particularly evident in the standing long jump, where the disparity grew from a small effect size ($d=.36$) at age 10 to a very large effect ($d=2.22$) at age 18. Similarly, the disparity in push-ups increased from $d=.09$ at age 10 to $d=.92$ at age 18. The explained variance due to sex differences was substantial, confirming the dominant role of biological factors in shaping strength development during adolescence [17, 18]. Similarly, anthropometric disparities also increased with age, with the strongest effects observed in standing long jump, where the marginal effect grew from $r=-.60$ at age 10 to $r=-.91$ at age 18. These findings emphasize that BF% plays an increasingly influential role in strength performance over time, reinforcing the need for individualized training and interventions addressing anthropometric differences. This supports prior studies demonstrating that increased body fat/weight and specifically adiposity negatively

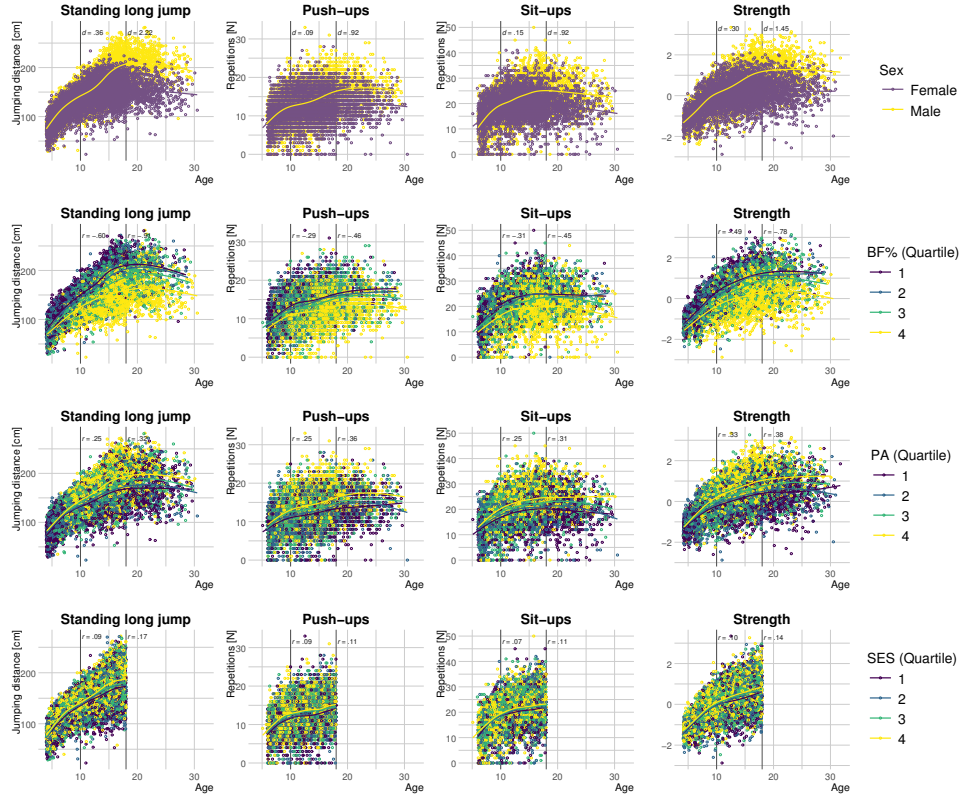


Fig. 1: Physical strength disparities across sex, body fat percentage, physical activity, and socioeconomic status.

Note: BF% = Body fat percentage, PA = Physical activity, SES = Socioeconomic status. For visualization and interpretation, the continuous dependent variables (BF%, PA, and SES) were divided into quartiles.

impact the performance on strength tasks [19, 20, 22–24]. Furthermore, PA disparities increased with age, reinforcing the importance of PA in strength development. The marginal effects at age 10 were modest ($r = .25$ across all strength tasks) but increased notably by age 18 (ranging from $r = -.31$ (sit-ups) to $r = -.36$ (push-ups)). This trend highlights the need for sustained PA throughout adolescence. These findings align with previous research showing that PA is associated with higher muscular fitness and better strength trajectories over time [20, 23]. Conversely, SES-related disparities were relatively minor, contributing little additional explained variance. The marginal

effects remained consistently low, indicating that socioeconomic differences had limited impact on strength development. Prior research suggests that lower-income groups tend to exhibit reduced muscular fitness [20, 23, 25], and our findings support that claim. The weaker role of SES in strength development is expected, as SES influences outcomes primarily through mediating factors.

4.1 Research implications

Our findings have important implications for physical education and youth training programs, as muscular fitness is strongly associated with favorable health outcomes [1, 12–14]. The pronounced influence of sex on strength disparities is largely attributable to fundamental genetic differences, which are only marginally modifiable. Nonetheless, promoting muscular fitness in females remains essential given its substantial health benefits [1, 12–14]. Addressing growing anthropometric disparities is equally important, as interventions targeting body composition may help reduce performance gaps and improve health outcomes [1]. PA also emerged as a key determinant of strength development. Thus, encouraging regular participation in muscle-strengthening and general PA from early childhood is imperative. Supporting this, the World Health Organization recommends muscle-strengthening activities across all age groups to maintain and enhance overall health [16]. Although SES disparities were minimal - likely reflecting its role through mediating factors - ensuring equitable access to physical activity resources and structured programs remains an important policy goal. Collectively, these findings highlight the need to promote muscular fitness from early childhood onwards, particularly as lifelong muscle strengthening is linked to improved quality of life and longevity [55].

599 Future research should explore further factors such as genetic predispositions,
600 nutritional status, and psychological influences on physical strength disparities. Lon-
601 gitudinal studies with large, representative populations could further validate these
602 findings. The use of body fat percentage in this analysis provided valuable insights,
603 but future studies should also consider additional body composition indicators, such
604 as muscle mass distribution and fat-free mass. Additionally, a more differentiated view
605 of physical activity in terms of intensity could provide deeper insights into the physical
606 strength disparities.
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613 4.2 Strengths and limitations

614 A key strength of this study is the use of a large, nationally representative dataset from
615 the MoMo study, allowing for robust and generalisable findings on strength disparities
616 in German youth. The combination of longitudinal and cross-sectional data provides
617 valuable insights into strength development across different age groups. Additionally,
618 the use of standardised physical fitness assessments ensures high measurement reli-
619 ability. Furthermore, the application of GAMLSS provides significant advantages in
620 addressing heteroscedasticity and non-linearity in the data, resulting in more accurate
621 and flexible estimations. However, certain limitations should be considered. First, the
622 reliance on self-reported PA data may introduce bias, as participants might overesti-
623 mate or underestimate their activity. Second, while bioelectrical impedance analysis
624 provides useful information on body composition, it may not capture muscle mass
625 distribution with the same precision as more advanced imaging techniques. Finally,
626 our study focused on specific strength measures, and future research should consider
627 incorporating a broader range of strength assessments to capture the full spectrum of
628 muscular fitness.
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5 Conclusion	645
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In conclusion, our study provides critical evidence on strength disparities in a nation-	647
ally representative sample of German youth. These insights contribute to a deeper	648
understanding of strength development and underscore the importance of targeted	649
interventions to enhance muscular fitness. The MoMo study's large-scale design pro-	650
vides a strong foundation for future research, and continued monitoring of these	651
disparities can inform policies to improve youth fitness and health outcomes.	652
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Supplementary information. No supplementary file/s.	654
	655
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Declarations	663
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‘long-term studies‘ in public health research.	672
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Conflict of interest/Competing interests	677
	678
The authors declare no conflict of interest/competing interests.	679
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Ethics approval and consent to participate	683
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All procedures performed in studies involving human participants or on human tis-	685
sue were in accordance with the ethical standards of the institutional and/or national	686
research committee and with the 1975 Helsinki Declaration and its later amendments	687
or comparable ethical standards. For the MoMo-Study, ethics approval was obtained	688
	689
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691 from the Charité Universitätsmedizin Berlin ethics committee, the University of Kon-
692 stanz, and the ethics committee of the Karlsruhe Institute of Technology. The Federal
693 Commissioner for Data Protection and Freedom of Information was informed about the
694 study and approved it. Informed consent was obtained from all individual participants
695 included in the study.

700 **Consent for publication**

702 Not applicable.

705 **Data availability**

707 The datasets generated and analysed during the current study are not publicly avail-
708 able due to the strict ethical standards required by the German Federal Office for the
709 Protection of Data, to which study investigators are obliged to comply, but are avail-
710 able from the project management of the MoMo study at the Karlsruhe Institute of
711 Technology upon reasonable request.

717 **Materials availability**

719 Not applicable.

722 **Code availability**

724 Not applicable.

727 **Author contribution**

729 TK, AHD, and SM conceptualized this paper. TK and LK acquired the data. TK, SM,
730 and AK developed and conducted the statistical analysis. All authors were involved
731 with the interpretation and review of the results. TK, AHD, and SM drafted the
732 manuscript. TK revised the manuscript according to feedback from all authors, who
733 were involved in critical revisions and provided important intellectual content.

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