Handgrip strength is associated with improved spirometry in adolescents

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Abstract

Introduction

Pulmonary rehabilitation, including aerobic exercise and strength training, improves function, such as spirometric indices, in lung disease. However, we found spirometry did not correlate with physical activity (PA) in healthy adolescents (Smith ERJ: 42(4), 2016). To address whether muscle strength did, we measured these adolescents’ handgrip strength and correlated it with spirometry.

Methods

In 1846 non-smoking, non-asthmatic Germans (age 15.2 years, 47% male), we modeled spirometric indices as functions of handgrip strength by linear regression in each sex, corrected for factors including age, height, and lean body mass.

Results

Handgrip averaged 35.4 (SD 7.3) kg in boys, 26.6 (4.2) in girls. Spirometric volumes and flows increased linearly with handgrip. In boys each kg handgrip was associated with about 28 mL greater FEV1 and FVC; 60 mL/sec faster PEF; and 38 mL/sec faster FEF2575. Effects were 10–30% smaller in girls (all p < 0.0001) and stable when Z-scores for spirometry and grip were modeled, after further correction for environment and/or other exposures, and consistent across stages of puberty.

Conclusions

Grip strength was associated with spirometry in a cohort of healthy adolescents whose PA was not. Thus, research into PA’s relationship with lung function should consider strength...
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as well as total PA. Strength training may benefit healthy lungs; interventions are needed to prove causality.

Introduction

Physical activity (PA) has been reported to protect against chronic diseases, such as cardiovascular disease, obesity and insulin resistance, [1] across the lifespan. Pulmonary benefits appear to be heterogeneous: PA is part of pulmonary rehabilitation for lung disease,[2] and higher PA levels are associated with better functioning in lung disease[3, 4] but in healthy young people the association is not as well studied and sometimes appears to be subgroup-specific [5] [6] or nonexistent.[7] PA is most often quantified as time spent in moderate or vigorous activity [8] [9] with less priority given to muscle-building resistance training.[10] However, muscle strength may be independently important.

Muscle-building interventions as short as a few weeks can increase levels of growth hormone and testosterone [11] in healthy adults, and increase bone density in aging women [12]; and resistance training is a standard component of pulmonary rehabilitation. [13] One common marker of general muscle strength is handgrip, [14–16] and interventions which improve upper-body strength also improve grip [17] so handgrip is gaining popularity as a robust and low-cost indicator of muscle strength. [14–16, 18, 19] In addition to being a general marker of good health in children [18] and adults, [20] grip strength is associated with better spirometric lung function in some studies of healthy children [21] and adults.[22] However, the association is best studied and proven for the elderly [13, 23] and those with obstructive lung diseases such as COPD [13], cystic fibrosis[24] and asthma, [25] in which weaker grip cross-sectionally indicates both presence and severity.

It is plausible that the observed positive relationships between PA and spirometric indices [3–5] may be explained partly by muscle strength, rather than or in addition to total activity. Athletes’ aerobic performance is often limited by respiratory-muscle fatigue [26, 27] which can be improved by targeted muscle training: inhaling or exhaling against resistance strengthens muscles involved in respiration, such as the diaphragm, intercostals and abdominals. [28] This improves inspiratory and expiratory flow rates in both healthy [28]and diseased [29] populations. It is thus plausible that strengthening the thoracic muscles in other ways, such as through resistance training, may also provide pulmonary benefits in health, as it is known to do in disease.[2, 30, 31] Indeed, spirometric indices often improve following participation in sports that exercise the thorax, such as swimming [32] and yoga. [33] However, although respiratory-muscle strength and/or pulmonary function often correlate with grip strength [21, 23, 29] the association is not well studied: these studies tend to be small, and many do not correct for body size or shape and thus may be confounded by them. Pairwise comparisons of groups (e.g. athletes vs. non-athletes, boxers vs. rowers[6]) may be especially vulnerable to such confounding, especially if one group is strongly selected. Furthermore, handgrip is so reliably associated with health that reduced grip may indicate frailty in general, rather than muscle strength in particular, when comparing patients to non-patients. Lastly, the known benefits of targeted muscle training in specific populations do not necessarily translate to an association between spirometric indices and handgrip muscle strength in healthy adolescents.

Our goal in this study was to establish whether strength was associated with better lung function in a healthy cohort where physical activity was not, [7] and thus to establish the plausibility of strength as a direct driver of improved spirometry in healthy lungs. In models corrected for confounders not of primary interest and limited to apparently lung-healthy
adolescents, we investigated the association between handgrip strength and spirometric indices.

**Methods**

**Study population**

We combined spirometry, physical examinations, and questionnaires from the 15-year follow-up of two German cohorts born between 1995 and 1999 and living in the regions of urban Munich and rural Wesel, GINIplus and LISAplus; in which we previously found no relationship between spirometry and accelerated PA.[7] GINIplus and LISAplus were approved by local Ethics Committees (Bavarian General Medical Council, Medical Council of North Rhine-Westphalia) and by written informed consent from participating families (parents or guardians.) We do not have the approval of the ethics committee nor of the subjects to make the data publicly available, but they are available to researchers who obtain approval of the GINIplus and LISAplus study steering committees (contact: Dr. Marie Standl, marie.standl@helmholtz-muenchen.de or Dr. Holger Schulz, schulz@helmholtz-muenchen.de) and the ethics committees and acceptance of a data transfer agreement from the legal department of the Helmholtz Zentrum München.

GINIplus was initiated to investigate the role of infant feeding on allergy development. Newborns with family history of allergy (N = 2252) were randomized in almost equal numbers to either partially or extensively hydrolysed whey, extensively hydrolysed casein, or cow’s milk formula; the remaining 3739 (the observation arm) were given no intervention formula. The current study samples both study arms, correcting for formula only as a confounder not of primary interest. (See S1 Text) Of the total 5991, 3199 were recontacted at age 15, of which 1801 completed handgrip testing and spirometry. Further details on study design, formulas and follow-up have been previously published [7, 34] and are in S1 Text.

LISAplus is a population-based cohort in the regions of Munich, Wesel, and also in Bad Honnef and Leipzig. No intervention, nutritional or otherwise, was used. Of 1812 subjects recruited at birth in Munich and Wesel (handgrip was not tested in Bad Honnef or Leipzig), 1107 were followed up at age 15, of which 529 completed handgrip tests and spirometry.

In both studies, sociodemographic data (parental education, birthweight, breastfeeding, pre- and postnatal tobacco exposure to age 6, pubertal status, asthma, and smoking at age 15) were reported at the initial survey (age 4–6 months) and followups to 15 years. Height, weight, lean body mass (LBM), handgrip and spirometric indices were measured objectively during the physical examination at 15 years.

Of the 2330 subjects from GINIplus and LISAplus who completed handgrip and spirometry at age 15, 1846 completed LBM measures and confirmed no asthma [35] or smoking. These 1846 are our current study population. Of these, 1574 had complete data on spirometric confounders such as environmental exposures (e.g. PM$_{2.5}$ and NO$_x$), 1598 had data on puberty, and 987 had accelerometer PA measured, and were thus included in the sensitivity analyses correcting for these factors.

**Spirometric protocol**

Spirometry was performed according to ATS/ERS recommendations, using a pneumotachograph-type spirometer (EasyOne Worldspirometer, ndd, Zurich, Switzerland) which has demonstrated volume accuracy of +/- 3% over at least four years with no significant nonlinearity. [36] Indices were taken from the maneuver with the largest sum of FEV1 and FVC[37]. A detailed protocol is given in S1 Text. Z-scores were calculated using reference values from the Global Lung Initiative 2012.[38] Because of the strong intercorrelation between spirometric
indices within subject, we considered all for which GLI predicted values were available and compared their results. Of particular interest was the comparison between peak expiratory flow (PEF), the most effort-dependent flow, and forced expiratory flow between 25 and 75% of FVC (FEF2575) as the least. We also considered forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio as indicator of airflow limitation.

**Grip-strength protocol**

Handgrip strength, quantified as the average of the better of two tests for each hand in accordance with the protocol in the PURE study[20] was measured using a validated TKK 5101 Grip D Dynamometer adjusted to fit the handspan of each subject, as detailed in the HELENA study. [18] For each hand subjects were instructed to let the arm hang free, squeeze the handle as hard as possible, and hold for two seconds; then release. Grip strength was measured to an accuracy of 0.1 kg. Z-scores for grip strength were calculated based on age from the HELENA study [18].

**Statistical methods**

All analyses were conducted using Statistical Analysis System (SAS) 9.2 or 9.3. All analyses were stratified by sex. P-value for significance was 0.05. Each spirometric index was modeled as normally-distributed linear function of grip strength and other confounders.

Because most spirometric indices correlate with each other, many models will be similar. We present models of all four indices to allow intercomparison between them and with models presented in the literature.

Linearity of associations was confirmed for all models by visual comparison of the regression line to a locally-weighted curve (LOESS) fitted in SAS, which found no inflection points or indications of threshold or ceiling effects. Inspection of q-q plots confirmed normality for grip strength in each sex and for all spirometric indices except FEV1/FVC, which was slightly skewed: however, the associations we found were still close to linear.

To check for effect modification, several nested models were fit. These are described below: confounders are described and defined in S1 Text.

**Basic model.** Preliminary analyses showed that, in addition to age, sex and height, spirometry was strongly associated with body frame size indicated as weight, body mass index (BMI), or lean body mass (LBM) as measured by bioelectric impedance. LBM was chosen as the best single indicator. Thus all models are corrected for LBM in addition to cohort-specific effects (nutritional intervention and study center Munich vs. Wesel), as well as age and height for models which use raw values rather than Z-scores.

**Correlates of lung function.** This model additionally corrected for correlates of lung health that were included when we found spirometry was not associated with physical activity.[7] These were parental education, BMI, birthweight, breastfeeding duration, pre- and postnatal tobacco-smoke exposure and air pollution (annual exposure to PM$_{2.5}$ and NO$_x$.)

**Puberty.** Puberty is associated with upper-body strength and growth rate, so in those who provided data we corrected for 5-level pubertal category using a validated self-report scale [39] based on the well-known Tanner scale.

**Physical activity.** Although we had found no link between PA and spirometry in this cohort, to be on the safe side we corrected for mean daily minutes moderate-to-vigorous PA in those 987 subjects (53%) with accelerometry. Accelerometry recruitment, protocols, data handling, and findings have been previously published [34] and are in S1 Text.
**Predicted values.** Spirometry and grip strength are strongly associated with age and height [38, 40] and the relationship for spirometry is nonlinear [38] so we also modeled Z-scores for spirometry [38] as function of Z-scores for grip strength. [18, 40]

**Results**

**Study population**

The current study population of non-smoking, non-asthmatic adolescents was representative of the 15-year followup of GINIplus and LISAplus. (Table 1) Boys were likeliest to be mid- or

| Table 1. Population characteristics. | Boys | Girls |
|--------------------------------------|------|------|
| N                                    | 1846 |      |
| Male, N, %                           | 867  | 47   |
| Age at exam, years                   | 15.2 | 0.28 |
| Height, cm                           | 176  | 7.6  |
| Weight, kg                           | 64.8 | 12.8 |
| BMI, kg/m$^2$                         | 20.7 | 3.3  |
| Lean body mass, kg                   | 51.9 | 8.1  |
| From Munich, %                       | 57   |      |
| Parents highly educated, %¹          | 68   | 70   |
| Valid spirometry, %                  | 100  |      |
| Valid grip-strength data, %          | 100  |      |
| Pubertal stage, %²                   |      |      |
| 1 (pre-pubertal)                     | 0.4  | 0    |
| 2 (early pubertal)                   | 4.8  |      |
| 3 (mid-pubertal)                     | 37.7 | 4.6  |
| 4 (late pubertal)                    | 55.7 | 78.7 |
| 5 (post-pubertal)                    | 1.3  | 16.8 |
| Spirometry                           |      |      |
| FEV1, L                              | 3.84 | (0.65)|
| FVC, L                               | 4.51 | (0.76)|
| FEV1/FVC, %                          | 85.3 | (6.1)|
| PEF, L/sec                           | 7.70 | (1.3)|
| FEF2575, L/sec                       | 4.13 | (1.0)|
| Spirometry; Z-score³                 |      |      |
| FEV1                                 | -0.55| (0.97)|
| FVC                                  | -0.56| (0.95)|
| FEV1/FVC                             | -0.05| (0.96)|
| FEF2575                              | -0.43| (0.96)|
| Grip strength, kg                    | 35.4 | (7.2)|
| Grip strength; Z-score³              | -0.58| (1.0)|

1) Higher-educated parent entered university or higher.
2) Pubertal stage from validated self-report scale [39] based on the Tanner scale [42, 43].
3) From Global Lung Initiative, 2012. [39] Predicted values do not exist for PEF.
4) Grip measured as average of both hands, with each hand best of up to 2 trials.
5) Predicted values from HELENA study [18]

All measures given as % of those with data; centrally-distributed measures given as mean (SD) unless otherwise stated.

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late-pubertal (stages 3 and 4) while girls tended to be late- or postpubertal (stages 4 and 5.) Previous research [7] found the 15-year followups had less exposure to tobacco, were drawn from more highly educated and urban families, and were likelier to be female than those lost to followup: and their height, weight, and BMI fit a German reference. [41]

**Lung function**

FEV1 and FVC averaged 3.84 (SD 0.65) and 4.51 (0.76) L for boys, 3.21 (0.43) and 3.65 (0.51) for girls. FEV1, FVC and FEF2575 were about half a standard deviation below predicted values in both sexes (GLI predicted values do not exist for PEF.) However, FEV1/FVC was close to predicted.

**Grip strength**

Boys' and girls' grip strength averaged 35.4 (SD 7.2; range 16.6–64.5) and 26.6 (4.1; 14.7–42.4) kg; Z-scores [18] were -0.58 (1.0) and 0.01 (0.86).

**Spirometric indices and grip strength**

Spirometric volumes (FEV1, FVC) and flows (FEF2575, PEF) were significantly and linearly associated with grip strength (Table 2, Fig 1). After correction for the age of height and LBM, each additional kg of grip strength in boys was associated with 29 mL greater FEV1, and 28 mL greater FVC. For girls the corresponding numbers were 20 mL FEV1 and 21 mL FVC (all p<0.0001). Flows were also elevated with greater handgrip strength, with each kg of grip strength associated with 59 mL/sec greater PEF and 38 mL/sec greater FEF2575 in boys, 53 and 30 mL/sec in girls (all p<0.0001.) FEV1/FVC was also elevated in stronger adolescents, but the effect was only significant in boys (0.10%/kg, p = 0.02.)

Effect sizes were only slightly smaller in the models corrected for BMI and/or weight in addition to LBM; correlates of lung function; puberty; or PA (Table 3). Effects for boys and girls were comparable across pubertal stages (Fig 2) The index with most variance explained by grip strength was usually FEV1, but occasionally PEF. Relationships between spirometry and grip strength (Fig 1) were close to linear even for the skewed FEV1/FVC. Models that did not consider any measure of body frame size (BMI, LBM, or weight) found effects about 30% larger (not shown.)

### Table 2. Spirometric indices and grip strength. Basic Model. Corrected only for age, height, lean body mass, nutritional intervention, and study center (Munich/Wesel).

|       | Grip strength, kg | % of variance explained by grip | % of variance explained by full model |
|-------|-------------------|--------------------------------|--------------------------------------|
| Boys  |                   |                                |                                      |
| FEV1, mL | 28.52            | 3.05                           | 0.096                               | 4.66                                  | 58.3                                    |
| FVC, mL | 28.23            | 3.05                           | 0.096                               | 3.40                                  | 65.6                                    |
| PEF, mL/sec | 59.49          | 7.25                           | 0.096                               | 5.01                                  | 35.6                                    |
| FEF2575, mL/sec | 38.01       | 6.17                           | 0.096                               | 3.43                                  | 22.0                                    |
| Girls |                   |                                |                                      |
| FEV1, mL | 20.12            | 3.29                           | 0.096                               | 2.40                                  | 38.3                                    |
| FVC, mL | 20.52            | 3.70                           | 0.096                               | 1.78                                  | 44.5                                    |
| PEF, mL/sec | 52.68          | 8.44                           | 0.096                               | 3.36                                  | 17.1                                    |
| FEF2575, mL/sec | 29.60        | 7.39                           | 0.096                               | 1.51                                  | 9.37                                    |

**Bold text** for index with most variance explained by grip for that sex.

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When spirometric Z-scores were modeled (Table 4) grip strength Z-score explained about 6% of the remaining variance in boys’ FEV1 and FVC, 2.5% of variance in boys’ FEF2575, and half that for girls (3.5 and 1.4%, respectively).

Discussion

We found that grip strength was positively associated with lung volumes and flows, corresponding to 250–300 mL FEV1 per standard deviation of handgrip strength.[14–16] and interventions which improve upper-body strength can also improve grip [17] and/or spirometry [6] [32] [44] [33] it is plausible that both handgrip and spirometric indices can be improved by exercises which strengthen the upper-body musculature. Further support is given to this by the close correlations between handgrip and the strength of the respiratory muscles. [45] While interventions are needed to prove causality, we suggest that strength training be added to the physical-activity recommendations for lung-healthy populations[10] as it has been to those with lung disease. [2, 13]
Our study population is among the first in which physical activity and handgrip strength were considered as independent correlates of spirometry, and thus we were able to establish the plausibility of various causal links. Since spirometry was associated with handgrip but not PA, and PA did not significantly modify the association between spirometry and handgrip, total PA cannot be mediating the association between spirometry and handgrip in this population. Similarly, Greutmann et al. found that although 40 young heart-disease patients reported they were as physically active as healthy controls, they still had weaker handgrip and respiratory muscles, which suggests that their physical activity was the wrong type, or insufficiently intense, to build those muscles. It thus appears that total physical activity may have different correlates from strength-building specifically: indeed, previous research with a subset of our population found that muscle-building exercise made up a relatively small fraction of total sporting activity, compared to aerobic team sports such as jogging and football. To avoid underestimating the benefits of physical activity, research into its correlates should consider the type of activity, or include measures of strength.

Our estimated association between spirometry and upper-body strength is consistent with earlier research on athletes whose sport strengthened the upper body: FEV1 was higher for athletes than nonathletes, with effect sizes ranging from 14% (Védala et al. to 30%
Our association is somewhat smaller than this, but our study is both larger and less confounded: we corrected not only for height but also for body proportions indicated by LBM. Residual confounding is still possible, since LBM includes leg muscles as well as chest; however, we found that adding LBM to a model of spirometry which considered height only decreased the association with grip by about 30%. Thus unmeasured variations in body proportions within this homogeneous population (ethnic Germans ages 14–17) would have to be quite large and nearly constant across pubertal stages to completely eliminate the remaining association. The same is true for other confounders, such as pollution exposure.

Our study objectively measures the correlates of interest (handgrip strength and spirometric indices) and the observed association was not confounded by known correlates of strength and lung function. However, selection occurred from initial recruitment (ethnic Germans) to followup at age 15; and completion of questionnaires and physical exam. Likewise, age range was narrow: our effects may be specific to young subjects, whose lungs have not fully matured and alveolarised. However, lung aging appears to be slower in active adults [47] suggesting...
that healthy aging lungs also benefit from PA. Lastly, we measured some environmental exposures over a longer period than others and thus some confounding may remain.[25]

**Conclusion**

We show that muscle strength (here quantified as handgrip) was associated with better lung function even in healthy young people without known lung disease. Previous research with this same population showed that the association was not driven by general physical activity, suggesting that the correlates of strength (and therefore, perhaps also the results of strength training) differ from those of aerobic physical activity. While interventional data are needed to establish causation, clinical recommendations and PA interventions should consider including a strength-training component. Furthermore, we suggest that research into the association between PA and spirometry either explicitly consider the type of PA or also consider measures of strength, such as handgrip, as indicators of physical condition.

More generally, we find that the value of grip-strength testing is not limited to elderly and aging populations, but is also present in this cohort of healthy adolescents. Handgrip may serve as a low-cost, objective and safe indicator of physical condition for researchers and clinicians.

**Supporting information**

S1 Fig. Recruitment for GINIplus and LISAplus cohorts from birth to the current study and sensitivity analyses.

(TIF)

S1 Text. Details on recruitment of GINIplus and LISAplus, exclusion criteria for the current study, statistical models, choice of confounders, and protocols for grip strength and spirometry.

(DOC)

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Maia P. Smith had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
This study was part of the 15-year followup of two German birth cohorts, GINIplus (German Infant Study on the influence of Nutrition Intervention PLUS environmental and genetic influences on allergy development) and LISAplus (Influence of lifestyle factors on the development of the immune system and allergies PLUS the influence of traffic emissions and genetics). We thank the GINIplus and LISAplus Study Groups for all their excellent work. The GINIplus Study Group includes the following: Institute of Epidemiology, Helmholtz Zentrum München—German Research Center for Environmental Health, Neuherberg (J. Heinrich, I. Brüske, H. Schulz, C. Flexeder, C. Zeller, M. Standl, M. Schnappinger, M. Sußmann, E. Thiering, C. Tiesler); Research Institute, Department of Pediatrics, Marien-Hospital, Wesel (D. Berdel, A. von Berg, B. Filippiak-Pittroff); Ludwig-Maximilians-University of Munich, Dr von Hauner Children’s Hospital (S. Koletzko, K. Werkstetter); Department of Pediatrics, Technische Universität München and Deutsche Rentenversicherung Bayern (C.P. Bauer, U. Hoffmann); and IUF—Leibniz Institute for Environmental Research, Düsseldorf (B. Hoffmann, E. Link, C. Klümper, U. Krämer).

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