

# Hand-grip strength of young men, women and highly trained female athletes

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Accepted: 27 October 2006 / Published online: 22 December 2006  
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**Abstract** Hand-grip strength has been identified as one limiting factor for manual lifting and carrying loads. To obtain epidemiologically relevant hand-grip strength data for pre-employment screening, we determined maximal isometric hand-grip strength in 1,654 healthy men and 533 healthy women aged 20–25 years. Moreover, to assess the potential margins for improvement in hand-grip strength of women by training, we studied 60 highly trained elite female athletes from sports known to require high hand-grip forces (judo, handball). Maximal isometric hand-grip force was recorded over 15 s using a handheld hand-grip ergometer. Biometric parameters included lean body mass (LBM) and hand dimensions. Mean maximal hand-grip strength showed the expected clear difference between men (541 N) and women (329 N). Less expected was the gender related distribution of hand-grip strength: 90% of females produced less force than 95% of males. Though female athletes were significantly stronger (444 N) than their untrained female

counterparts, this value corresponded to only the 25th percentile of the male subjects. Hand-grip strength was linearly correlated with LBM. Furthermore, both relative hand-grip strength parameters ( $F_{\max}$ /body weight and  $F_{\max}$ /LBM) did not show any correlation to hand dimensions. The present findings show that the differences in hand-grip strength of men and women are larger than previously reported. An appreciable difference still remains when using lean body mass as reference. The results of female national elite athletes even indicate that the strength level attainable by extremely high training will rarely surpass the 50th percentile of untrained or not specifically trained men.

**Keywords** Strength · Gender · Trainability · Lean body mass · Ergonomic references

## Introduction

Manual lifting and carrying of loads are common types of exercise in everyday life at home and at work. Despite the application of high technology at work, there are still physically demanding occupations in fields such as automotive industries, manual material handling jobs, postal, emergency and military services. In the last two decades there has been a large increase in the number of women employed in these traditionally male-dominated occupations (Bhambhani and Maikala 2000; Haward and Griffin 2002). Generally, the absolute loads to be handled on the job are similar for men and women (Bhambhani and Maikala 2000; Rice et al. 1996a). Since hand-grip strength has been identified as a limiting factor for manual carrying (Bhambhani and Maikala 2000; Byström and Fransson-Hall 1994;

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Kilbom et al. 1992; Knapik et al. 1999; Rice et al. 1996a, b; von Restorff 2000), assessment of hand-grip strength could be used for pre-employment screening and selection.

For a given hand-grip ergometer, measurements are reliable, safe, easy and fast to perform (Haidar et al. 2004; Haward and Griffin 2002; Leyk et al. 2006; Rantanen et al. 1998). Moreover, normative hand-grip strength data are not only essential for the prevention of manual lifting hazards, but also of paramount importance in determining the effectiveness of various surgical or treatment procedures (Mathiowetz et al. 1985; Rauch et al. 2002).

Despite its fundamental importance for occupational and clinical practice, only few studies provided hand-grip strength data of large study populations, typically in the order of some 100 healthy individuals (Bao and Silverstein 2005; Barnekow-Bergkvist et al. 1996; Haidar et al. 2004; Hanten et al. 1999; Kallman et al. 1990; Kellor et al. 1971; Massy-Westropp et al. 2004; Mathiowetz et al. 1985; Sinaki et al. 2001). However, these data have to be interpreted with some caution as recently suggested by Luna-Heredia et al. (2005). All studies comprised study populations of men and women with age spans of many decades. For epidemiological purposes the investigated numbers of subjects were too small for a detailed age and gender related stratification. Since hand-grip strength is influenced by various factors (gender, age, physical fitness, etc.), reference values for hand-grip strength should be determined in large and well-characterized groups.

The present study has three major aims: (1) in order to provide epidemiologically relevant normative hand-grip strength data for pre-employment screening and selection, we investigated young, healthy women and men aged between 20 and 25 years. (2) To evaluate the potential influence of biometric factors on hand-grip strength, anthropometric measures such as hand length, hand width and lean body mass were taken from the subjects. (3) It is well known that women possess considerably smaller absolute muscle strength than men. When women have to be assigned to physically demanding workplaces with similar absolute loads for both sexes (e.g. military services, fire fighter), it is of paramount importance to estimate the potential margin of improvement in muscle strength by exercise and training. Therefore, we investigated highly trained female athletes from sports, which are known to require high hand-grip strength (judo and handball). Such collectives of female elite athletes provide an excellent opportunity to study the strength level attainable by daily physical training over years. The results from these elite athletes can serve as a measure

for the maximal trainability attainable for young, healthy women.

## Methods

### Subjects

Our nationwide recruited study sample comprised 2,247 young healthy adults (1,654 men, 533 women and 60 female national elite athletes). The subjects of the non-athlete groups were untrained or not specifically trained young adults with a typically German education distribution as estimated by the latest official census (Mikrozensus 2004). This group covers the whole range of employment status from jobless persons without any certificate, up to employed persons and university students. The female elite athletes were members of national teams.

The basic characteristics are shown in Tables 1 and 2. Prior to examination the volunteers were informed about the purpose and the procedures of the investigation and gave their written consent. Additional information about the athletics status of all participants was assessed by means of a questionnaire. All subjects were familiarized with the test procedures and were tested to obtain anthropometric and hand-grip strength data. The study was approved by the Ethics Committees of the German Sport University and the Medical Association of the Federal State Rhineland-Palatinate, Germany.

### Anthropometry

In addition to body height and body weight additional information about the percentage of body fat could be assessed in 1,553 men, 482 women and in all female athletes. For that purpose the skinfold thickness at four sites—biceps, triceps, subscapular and suprailiac—was determined by means of Harpenden calipers (Harpenden Skinfold Caliper HSK-BI, British Indicators, West Sussex, United Kingdom). Values were measured three times to the nearest 0.2 mm. If results deviated more than 1.0 mm, the three measurements were repeated. The sum of the four skinfold measurements was evaluated according to the equations of Durnin and Womersley (1974). Absolute and percent lean body mass (LBM) were calculated from body fat (%) and body weight (kg):

$$\text{LBM (\%)} = [100 - \text{fat (\%)}],$$

$$\text{LBM (kg)} = \left[ \frac{\text{weight} \times \text{LBM (\%)}}{100} \right]$$

**Table 1** Anthropometric characteristics of young adult men and women

Variables	Mean (SD)	5th	25th	Median	75th	95th	
<i>Men</i>							
<i>n</i> = 1,654	Age (year)	21.4 (1.4)	20	20	21	22	24
<i>n</i> = 1,654	Weight (kg)	78.2* (12.1)	61.74	69.80	76.65	84.90	100.90
<i>n</i> = 1,654	Height (cm)	180* (0.7)	169	175	180	185	191
<i>n</i> = 1,654	BMI (kg m <sup>-2</sup> )	24.1* (3.3)	19.67	21.84	23.75	25.86	30.26
<i>n</i> = 1,553	Fat (%)	18.7* (5.9)	9.95	14.18	18.08	23.01	28.79
<i>n</i> = 1,553	Lean body mass (kg)	63.2* (7.1)	52.62	58.27	62.73	67.76	75.60
<i>Women</i>							
<i>n</i> = 533	Age (year)	21.5 (1.4)	20	20	21	22	24
<i>n</i> = 533	Weight (kg)	64.1 (11.2)	51.06	56.70	62.60	69.50	82.43
<i>n</i> = 533	Height (cm)	167 (0.6)	158	163	167	171	178
<i>n</i> = 533	BMI (kg m <sup>-2</sup> )	23.0 (3.7)	18.74	20.59	22.45	24.78	28.56
<i>n</i> = 482	Fat (%)	30.8 (5.5)	22.34	26.78	30.45	34.95	40.05
<i>n</i> = 482	Lean body mass (kg)	43.7 (4.5)	37.33	40.45	43.39	46.26	51.47

Values are means ± SD and percentile ranges

\**P* < 0.001, significant between gender

**Table 2** Anthropometric data of national female elite athletes

Variable	All athletes ( <i>n</i> = 60)	Range	Judo ( <i>n</i> = 45)	Range	Handball ( <i>n</i> = 15)	Range
Age (years)	19.8 ± 4.1	15–31	18.8* ± 3.4	15–31	22.6 ± 4.7	16–30
Height (cm)	171 ± 0.5	157–182	171 ± 0.6	157–182	172 ± 0.5	165–180
Weight (kg)	71.2 ± 13.3	53.6–130.6	72.5 ± 15.0	53.6–130.6	68.7 ± 4.8	61.9–80.0
BMI (kg m <sup>-2</sup> )	24.2 ± 3.8	18.3–40.3	24.5 ± 4.11	18.3–40.3	23.3 ± 2.3	20.1–28.7
Fat (%)	26.4 ± 5.6	15.3–43.9	26.7 ± 5.7	16.6–43.9	25.6 ± 5.5	15.3–34.9
Lean body mass (kg)	51.9 ± 6.1	40.0–73.4	52.2 ± 6.9	40.0–73.4	51.0 ± 2.7	45.2–54.3

Values are means ± SD and absolute range (*n* = 60)

\*Significant between the athlete groups (*P* < 0.01)

To evaluate the relationship between LBM and maximum hand-grip strength LBM-groups were assigned to ten consecutive 5-kg-classes ranging from 35 to 85 kg.

**Hand-grip force**

Maximal isometric hand-grip force was recorded over 15 s using a handheld hand-grip ergometer shown in Fig. 1. Force (*F*) was measured by a strain gauge sensor (K-2565, Lorenz Messtechnik Ltd., Alfdorf, Germany; measuring range: 1,500 N; accuracy: 0.1%) at a sampling frequency of 50 Hz (750 data points for each 15 s

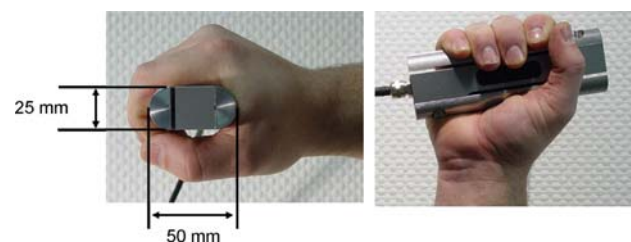
test). During measurement, upper and lower arm were supported in such a way that a 90° position of the elbow joint was achieved without additional effort (Fig. 2). The following parameters were derived from the 15 s force tracings:

- (1) Maximum hand-grip force (*F*<sub>max</sub>): the maximum value out of all 750 data points for each 15 s test.
- (2) Mean hand-grip force (*F*<sub>mean</sub>): the arithmetic average of the 750 data points.
- (3) Percent *F*<sub>mean</sub> (*pF*<sub>mean</sub>): *F*<sub>mean</sub> expressed as percentage of *F*<sub>max</sub>.
- (4) Relative hand-grip forces: *F*<sub>max</sub> per kg body mass or LBM.

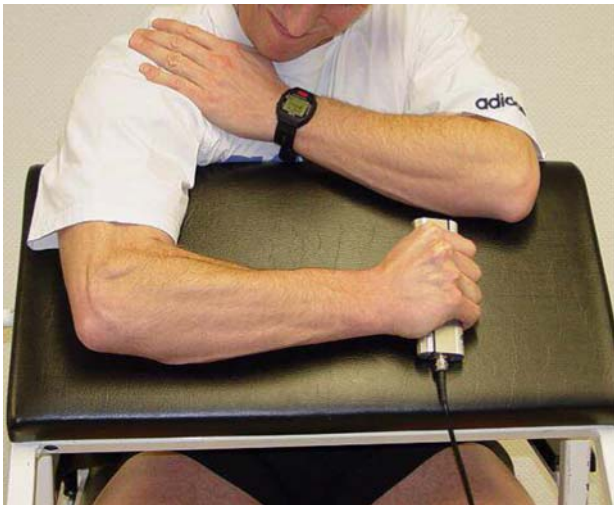
To assess the potential influence of hand dimensions on hand-grip strength, hand length and width were measured in 1,142 male and 338 female volunteers as described by Jürgens (2000) and Martin et al. (1991).

**Statistical analyses**

Statistical analyses were performed using SPSS™ 12.1 and STATISTICA™ 7.1. Data are generally given as



**Fig. 1** Hand-grip ergometer: length 150 mm; mass 1.1 kg



**Fig. 2** Exercise position during the hand-grip test

means and standard deviation (SD). The comparisons of hand-grip strength data between the male and female control group and the trained female subjects are presented as median and interquartile range (box-plot). Independent Mann–Whitney  $u$ -test was used to compare average hand-grip forces and anthropometric data. The mean time courses of hand-grip force were investigated by two-way ANOVA for repeated measures (factors “gender” and the 15 s “test-time”). Maximum hand-grip force values of different LBM-groups were analysed by two-way ANOVA (factors “gender” and “LBM-groups”). The Newman–Keuls test was used for post hoc comparisons. Linear regression and Spearman correlation coefficients were computed for  $F_{\max}$  and LBM-values as well as for  $F_{\max}$  and  $pF_{\text{mean}}$  of men and women, respectively. In addition, multiple regression analysis was applied to investigate the influence of gender and anthropometric characteristics on hand-grip force. The backward analysing method was used. Significance level was chosen as  $P = 0.01$ .

## Results

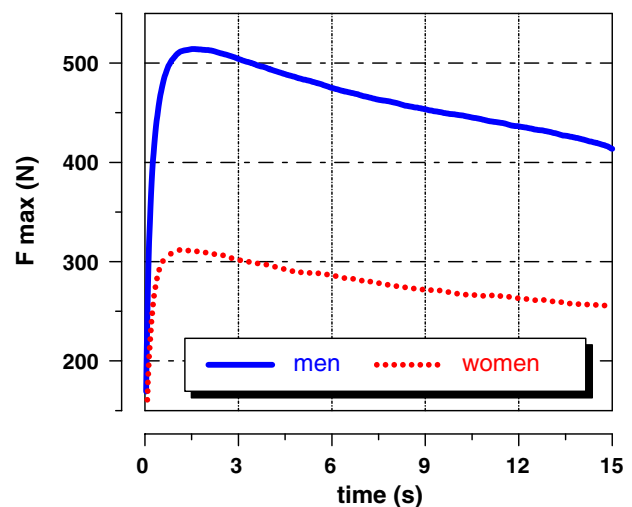
Relevant anthropometric characteristics of the young adult control groups are shown in Table 1. With the exception of age all biometric values revealed significant differences between men and women ( $P < 0.001$ ).

Hand-dimensions had no significant influence on hand-grip strength per kg body mass ( $F_{\max}$ /body weight). This applies to both hand length (men:  $r = -0.03$ ,  $P = 0.196$ ; women:  $r = 0.12$ ,  $P = 0.027$ ) and hand width (men:  $r = -0.01$ ,  $P = 0.745$ ; women:  $r = 0.03$ ,  $P = 0.471$ ). Furthermore, analysis of variance revealed

a significant effect of gender ( $P < 0.0001$ ) but not for hand length or hand width ( $P = 0.286$ ,  $P = 0.390$ ). Similar results were obtained when using hand-grip strength per kg LBM ( $F_{\max}$ /LBM) as reference.

Maximal (men:  $540.8 \pm 87.1$ ; women:  $329.4 \pm 57.7$  N) and mean hand-grip force (men:  $460.5 \pm 79.4$ ; women:  $277.8 \pm 52.8$  N) differed significantly between males and females. Figure 3 shows the mean time courses of hand-grip force of the male and female volunteers ( $n = 2,187$ ). Analysis of variance yielded a significant effect of “test time” (force time course,  $P < 0.001$ ), a significant influence of gender ( $P < 0.001$ ) and a statistically relevant interaction of the two factors ( $P < 0.001$ ). When expressed as %  $F_{\max}$ , the mean hand-grip force over 15 s of men and women showed only a negligible, though statistically significant difference (85.1% vs. 84.3%,  $P < 0.01$ ). However, there was no indication of relationship between  $F_{\max}$  and  $pF_{\text{mean}}$   $r = 0.10$  ( $Y = 83.22 + 0.004 \times F_{\max}$ ,  $P < 0.0001$ ,  $n = 2,187$ ): subjects with high, moderate or low maximum grip-force values sustained comparable percentage values of their hand-grip force maximum during the test interval (distribution: median = 85.6%, fifth percentile = 76.0%, 95th percentile = 91.5%,  $n = 2187$ ).

A more detailed insight into the gender related hand-grip distribution is given in Fig. 4. 90% of the female test persons produced maximal hand-grip forces smaller than the values of 95% of their male counterparts. The woman with highest hand-grip force reached only the 33rd percentile of the male volunteers.



**Fig. 3** Time courses of hand-grip forces of young male (solid curve) and female (dotted curve) adults aged 20–25 years. Values are means (men:  $n = 1,654$ ; women:  $n = 533$ ). For better illustration the SD bars are not shown (SD-range of men: 74–133 N; SD-range of women: 47–72 N)

Linear regression analysis revealed that hand-grip force was strongly associated with absolute lean body mass (LBM,  $R^2 = 0.765$ ). The LBM-associated force increase (Fig. 5) was significant for all LBM-groups ( $P < 0.0001$ ), and for the factor gender ( $P < 0.0001$ ) with virtually identical slopes in males and females ( $P = 0.612$ ) but different  $Y$ -intercept (men:  $Y = 193.8 \text{ N} + 5.5 \text{ N kg}^{-1}$ ; women:  $Y = 86.6 \text{ N} + 5.6 \text{ N kg}^{-1}$ ). If hand length or hand width are matched between men and women within an LBM-group of sufficient overlap (50–54.9 kg, male  $n = 70$ , female  $n = 18$ ) then the difference in maximum hand-grip strength persists (about 90 N,  $P < 0.0001$ ). Spearman correlation coefficients between the variables hand-grip strength and LBM were  $r = 0.453$  ( $P < 0.0001$ , men) and  $r = 0.440$  ( $P < 0.0001$ , women). Multiple linear regression analysis of the independent variables gender, body height and LBM revealed the following results: gender ( $P < 0.0001$ ) and LBM ( $P < 0.0001$ ) are positively and linearly related to grip-force values (model  $R^2 = 0.647$ ). In contrast to LBM, no statistically relevant influence was found for body height and body fat in both men and women.

Anthropometric characteristics of the female elite athletes (judokas and handball players) are given in Table 2. All parameters differ significantly between female controls and the trained women. The highly trained female athletes ( $F_{\max}$ :  $443.6 \pm 38.2$ ;  $F_{\text{mean}}$ :  $374.5 \pm 37.9$ ) were stronger than the female control group but still considerably weaker ( $P < 0.0001$ ) than most of the male volunteers (Fig. 6). The strongest female athlete had a maximal hand-grip force of 559 N

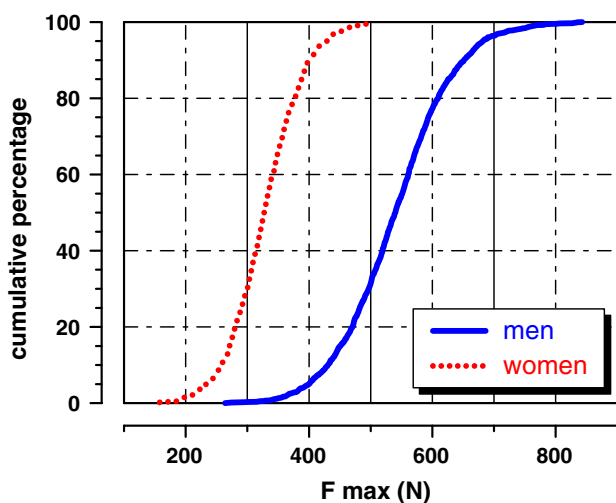
corresponding to the 58th percentile of the male volunteers.

## Discussion

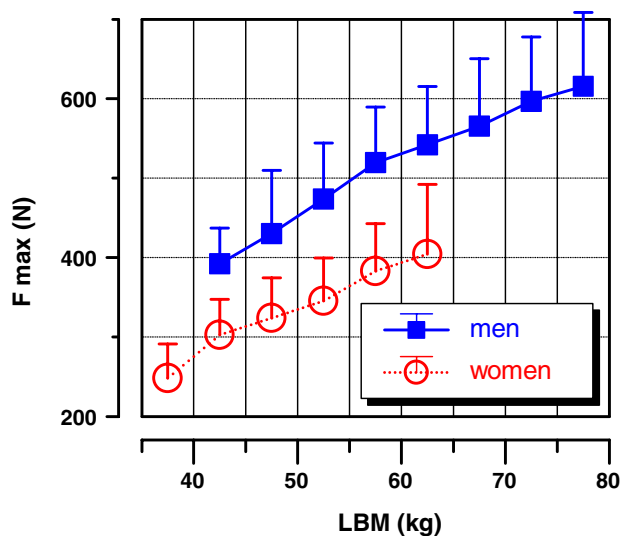
The main objective of our study was to establish hand-grip reference values of young adults for pre-employment screening and personnel selection. Such normative data are also needed in clinical practice, e.g. physiotherapy, hand surgery, pediatrics, gerontology (Haidar et al. 2004; Luna-Heredia et al. 2005; Mathiowetz et al. 1985; Rauch et al. 2002). In terms of absolute hand-grip strength our results indicate larger gender differences than previously reported (Laubach 1976; Heyward et al. 1986; Miller et al. 1993; Sinaki et al. 2001). Ninety percent of the women had lower  $F_{\max}$  values than 95% of the male control group (Fig. 4). The strongest female volunteer of our control group only achieved a maximal hand-grip value of only 505 N, which was exceeded by 2/3 of all men. The age-heterogeneity of other hand-grip force focusing study populations, covering up to eight decades, inevitably results in larger data scatter and overlaps between males and females (Kallman et al. 1990; Haward and Griffin 2002; Mathiowetz et al. 1985).

A significant gender difference of about 90 N persisted when maximal hand-grip strength was related to lean body mass (Fig. 5). This difference cannot be attributed to an inappropriate choice of ergometer dimensions since no influence of hand length or width could be detected. Clerke et al. (2005), who compared male and female teenagers, also failed to find significant effects of hand shape on maximal grip strength. Some studies indicate that sex-related strength differences are more pronounced in the upper body (Heyward et al. 1986; Laubach 1976; Miller et al. 1993). Therefore, the strength difference of Fig. 5 might at least partly be attributed to the fact that women tend to have a lower portion of their lean body mass located in the upper body (Miller et al. 1993). With regard to manual load-carriage tasks in the work environment, this would mean that women have to lift and carry loads with a smaller fraction of their already smaller absolute muscle mass.

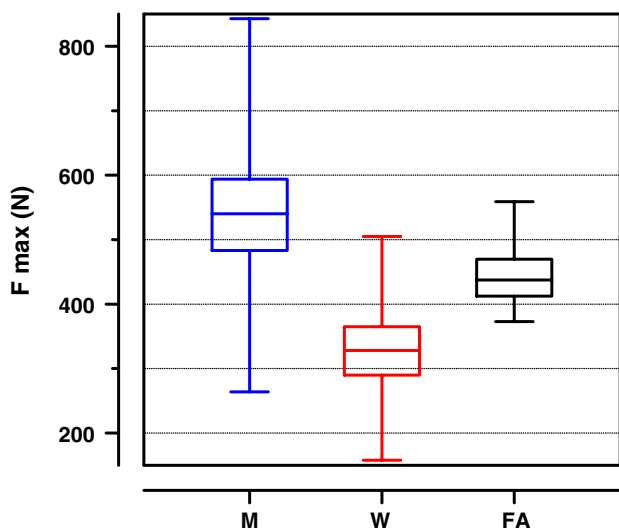
An example of a demanding manual exercise is stretcher transport (Barnekow-Bergkvist et al. 2004; Gamble et al. 1991; Knapik et al. 1999; Leyk et al. 2006). The sustained isometric hand-grip contraction and the eccentric strains during the transport require large hand-grip strength of ambulance personnel (Leyk et al. 2006). With regard to personnel selection and recruiting procedures for medical services, von



**Fig. 4** Distribution of maximum hand-grip forces ( $F_{\max}$ ) of male (solid curve) and female (dotted curve) volunteers (men:  $n = 1,654$ ; women:  $n = 533$ )



**Fig. 5** Male (squares) and female (circles) hand-grip forces ( $F_{\max}$ ) of different lean body mass groups (LBM). Values are means  $\pm$  SD (men:  $n = 1,553$ ; women:  $n = 482$ )



**Fig. 6** Maximum hand-grip forces ( $F_{\max}$ ) of young adult men (M,  $n = 1,654$ ), women (W,  $n = 533$ ) and female elite athletes (FA,  $n = 60$ ). Values are median  $\pm$  interquartile (25th and 75th percentile) and absolute range

Restorff (2000) proposed to consider only candidates whose grip strength at the weaker side exceeds 334 N. It can be taken from Fig. 4 that about 60% of our female volunteers would not have sufficient grip strength to meet this criterion.

Multivariate regression model including body height, gender and LBM revealed no relationship between body height and hand-grip strength. This is a remarkable difference to the approach of Frederiksen et al. (2006) who described body height-stratified

reference data. However, body weight, body fat and LBM were not measured in their study. The results of our broader approach, including the aforementioned biometric parameters revealed that hand-grip strength is not causally affected by body height per se, but rather predicted by LBM.

One might expect that strength training of women could eliminate the strength difference at least with regard to a group of not specifically trained males (Fig. 6). To our own surprise, the female elite athletes, though active in sports (handball and judo) where hand-grip strength is trained in each training session matched only the 25th percentile of the male control group.

We also observed that, independent of the strength level and for both sexes, volunteers were able to sustain about 85% of their individual  $F_{\max}$  during the 15 s hand-grip tests. Since maximal hand-grip tests strongly depend on cooperation and motivation of the test persons, the relation of the sustained and maximal hand-grip strength could be used to control data quality.

In conclusion, we found considerable differences in hand-grip strength between young male and female adults. The mean maximal hand-grip force differs by more than 200 N, with only a small overlap of strength distribution and no significant influence of hand size. Appreciable differences in the order of 100 N remain when using lean body mass as reference. Surprisingly, even the group of highly trained female athletes matched only the 25th percentile of our untrained or not specifically trained male controls.

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