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Force capacity of trunk muscle extension and flexion in healthy inactive, endurance and strength-trained subjects—a pilot study

Introduction

In our modern world, fewer and fewer physical demands act on our bodies. Ultimately, a low activity level leads to a reduction in physical performance (Hicks et al., 2005). In addition, a passive recreation style leads to reinforcing effects since high-calorie foods are often consumed, leading to weight gain and thus counteract the reduced energy demands (Chaput & Tremblay, 2009). Physical inactivity also leads to deconditioning of the trunk muscles, which is discussed as a possible cause of acute and chronic back pain or at least shows correlative relationships (Pranata et al., 2017).

On the other hand, recreational sports are gaining more attention. People do this with the awareness that adequate physical fitness is the basis for coping with everyday life and sustained physical and mental health (Chen et al., 2017; Reimers, Knapp, & Tettenborn, 2012). Furthermore, physical activity is attributed to positive effects on metabolic diseases (Defay et al., 2001), fracture susceptibility (Lange et al., 2007), and last but not least, a positive body image (Sabiston, Pila, Vani, & Thogersen-Ntoumani, 2019).

There is a wide variety of sports that can be practised, with different training objectives for each individual (Oja et al., 2015). Regardless of the type of sport practised (e.g. games, martial arts), different training modalities can be distinguished. Two contrasting but often compared training modalities are strength training and endurance sports (Leveritt, Abernethy, Barry, & Logan, 1999; Taipale, Mikkola, Vesterinen, Nummela, & Häkkinen, 2013). Strength training uses few repetitions of an exercise with near-maximal contractions. In endurance sports, many repetitions are performed in the submaximal range. Therefore, there are functional and metabolic differences in the musculature of strength and endurance athletes, which can be measured differently depending on the perspective of the study (Hawley, 2009; Hughes, Ellefsen, & Baar, 2018; Nader, 2006).

Functional testing of muscles is well established (Kendall, Kendall, Mc Geary, Provance, Rodgers, & Romani, 2005; Valerius et al., 2012) and performing maximal voluntary contraction (MVC) tests can be considered the gold standard for determining their maximal strength capacity (Kurz, Anders, Walther, Schenk, & Scholle, 2014; Meldrum, Cahalane, Conroy, Fitzgerald, & Hardiman, 2007; Shirado, Kaneda, & Ito, 1992). There are some studies that examined MVC specifically for limb muscles (Klein, Allman, Marsh, & Rice, 2002; Lanza, Towse, Caldwell, Wigmore, & Kent-Braun, 2003; Young, Stokes, & Crowe, 1985). Studies of trunk muscles are often conducted in the context of an ageing population (Doherty, Vandervoort, Taylor, & Brown, 1993; Kurz et al., 2014; Porter, Vandervoort, & Lexell, 1995). A frequently applied and widely studied test to especially examine trunk muscle endurance in the submaximal range is the Biering–Sorensen test (Biering Sorensen, 1984). Other studies deal with the relationship between trunk muscle performance and back pain (Cho et al., 2014; A. Keller et al., 2004). Normative values for trunk muscle strength in young healthy untrained subjects have been established (Anders, Brose, Hofmann, & Scholle, 2007; Troup & Chapman, 1969). One study investigated back muscle strength in healthy, predominantly endurance-oriented athletes (Ezechieli et al., 2013). Other studies compared trunk muscle strength of subjects who trained in different types of sports (Andersson, Sward, & Thorstensson, 1988; Zouita et al., 2019). However, to our knowledge, there has been no investigation of trunk muscle strength in subjects with the two general training modalities of strength training and endurance training. This could provide a better understanding of training-dependent adaptation mechanisms of trunk muscles and could be an enhancement to the standard values mentioned above.

We therefore asked ourselves whether the maximum strength capacity of trunk muscles is influenced by training modality and how this differs from the normal population. To investigate this, the

Table 1 Demographic characteristics of study participants. All values are displayed as mean values ± standard deviation (MV ± SD)

	ET	ST	C
Age (years)	22.2 ± 2.9	23.5 ± 1.8	22.1 ± 1.0
Height (cm)	184 ± 6.5	181 ± 5.6	184 ± 5.9
Weight (kg)	72.8 ± 7.0	90.3 ± 13.9*	78.9 ± 14.3
BMI (kg/m^2)	21.5 ± 1.3	27.7 ± 3.8*	23.1 ± 3.8**

BMI body mass index, *ET* endurance trained subjects, *ST* strength trained subjects, *C* inactive subjects/control group

*$p < 0.01$ vs. ET

**$p < 0.05$ vs. ST

present study compared the maximal strength capacity of trunk muscles between physically inactive individuals and ambitious recreational endurance and strength athletes. We expected a superiority of the strength athletes compared to the endurance athletes, who in turn should show larger strength values than the inactive subjects.

Methods

Participants

For this study, 38 healthy male participants were recruited by online announcement and personal contact. The investigated population consisted of a group of physically inactive people (Control [C], $n = 12$) and two groups of physically active people. The two physically active groups practised either endurance (ET; cycling and triathlon, $n = 13$) or strength training (ST; power lifting, $n = 13$). Training intensity was at competition level in both active groups with at least four training sessions per week and a training history of at least 4 years. ST trained at least 1 h and ET trained at least 2 h per day. ET did not perform any specific core strengthening. Participants who did both, strength training and endurance training, were not included. The inactive subjects showed only minor to moderate physical activity for several years (walking or participating in comparable activities once a week at most). Exclusion criteria were general health problems potentially interfering with the investigation, back pain in the last 3 months or any surgery of the back. Therefor a brief survey about the medical history and a clinical examination, which included clinical inspection and evaluation of percussion or compression pain across the whole spine and paravertebral muscles was performed by an experienced medical student. If participants showed signs of percussion or compression pain or spinal deformities, they were excluded from the study. None of our recruited subjects was dismissed. All participants were informed about the procedures and the aim of the study and signed informed consent to voluntary participate in this investigation. The study was approved by the local ethics committee (2020–1844–BO). Details about the demographic characteristics of the study participants are provided in ◘ **Table 1**.

Maximum voluntary contraction

Participants were positioned in a computerized test and training device (CTT Centaur, BfMC, Leipzig, Germany). In this device, the subjects' lower body is fixed, while the upper body remains free to a limited extent of motion. To measure the respective forces, the device is equipped with a harness, positioned over the subjects' shoulder. It contains strain gauges for force measurement in frontal and sagittal directions located at scapular spine height (sampling rate: 100/s). Thus, the force sensor was located at the subject's upper body segment (UBS; see below) length. For each task, participants were standing in upright position with their arms crossed at their chest. After a set of eight submaximal trunk flexion and extension tests in upright posture, participants performed a set of three isometric maximum voluntary contraction (MVC) tasks in flexion and extension directions at 0° trunk angle. At first, MVC tests in extension direction were performed with the first execution serving as the test trial at self-estimated intensity of about 50% MVC level. For that, participants had to push backwards into the harness with their maximum force (◘ **Fig. 1**). After these trials, the same procedure was applied in flexion direction. Each MVC task had a duration of 3–5 s. Between each trial, participants were given a 5 s break to recover and refocus. During the MVC trials all participants were supported by verbal encouragement (McNair, Depledge, Brettkelly, & Stanley, 1996). Best out of three trials for each extension and flexion MVC trials were used as MVC values for analysis.

Determination of torque values

The upper body weight (UBW) was determined for every participant. For this, subjects were tilted to horizontal position (90°), while leaning relaxed into the harness (◘ **Fig. 2**). Because of the gravitational forces acting on the trunk, the subject's UBW could be measured. During this procedure the contraction status of the trunk and especially the back muscles was verified by palpation. Remaining contractions were announced to the participant for correction. The largest trustworthy value out of three trials was considered as the UBW. The measured UBW values were then converted into torque values [N] (Anders, Brose, Hofmann, & Scholle, 2008; Huebner, Faenger, Scholle, & Anders, 2015; Kurz et al., 2014). Further, the force values were transformed into upper body torques (UBT) [Nm] (Holmström, Moritz, & Andersson, 1992) by correcting these values by the upper body segment (UBS) length (i.e. adjusting them to each individual anthropometry) to directly compare the MVC values between subjects. UBS was defined as the distance between palpable L4 spinous process and the medial border of the scapular spine.

MVC values were also further related to each subject's UBW, to relate the MVC values to the individual anthropometric conditions. This parameter was named torque ratio (Eq. 1).

$$torque\ ratio = \frac{MVC \times UBS}{UBW \times UBS} = \frac{maximum\ torque}{UBT} \quad (1)$$

This torque ratio was used for final decision making. Also, the extension to flexion ratio (ex/flex ratio) was determined for group comparisons. Both ex/flex ratio and torque ratio are unit-free values. Therefore, the main outcome parameters for the present study were maximum torque values, torque ratio, and ex/flex ratio.

Statistical analysis

Initially we applied an analysis of variance (ANOVA) to identify main group effects. For pairwise comparisons between groups Student's t-tests for independent groups were used. Beforehand, a normal distribution of the data was ensured (Shapiro–Wilk test). The global significance level was set at 5% ($p \leq 0.05$). As multiple pair wise tests were performed, a subsequent Bonferroni correction was applied. The respective p values will all be displayed after the correction, enabling clear readability by referencing all values to the global significance level of 0.05. Furthermore, effect sizes (Cohen's d) were calculated. Effect sizes were also calculated for nonsignificant results, as the inclusion of effect sizes is a valid method for comparisons with previous and future studies (Lakens, 2013). Especially for studies on strength training, there is a respective recommendation for this methodology (Rhea, 2004). Statistical analyses were carried out using SPSS 28.0 (IBM Corp., Armonk, NY, USA).

Results

The initial ANOVA revealed significant main effects for UBW, UBS and all maximum force or torque data (**Table 2**).

All outcome parameters together with the results of the group-wise statistical analyses (p values and effect sizes) are displayed in **Tables 3 and 4**. For both flexion and extension maximum torque levels were highest for the ST group (extension: $p < 0.05$ vs. ET; $p < 0.01$ vs. C; flexion: $p < 0.01$ vs. ET and C), whereas between ET and C groups, no systematic differences could be detected (extension and flexion: $p > 0.05$). For the determined torque ratios, the observed differences between ST and the other two groups decreased in magnitude; therefore the systematic differences were significant on a 5% level or were not significant at all (extension: $p < 0.01$ vs. C; flexion: $p < 0.05$ vs. ET; $p < 0.01$ vs. C). With respect to the ex/flex ratio, no systematic difference could be detected ($p > 0.05$ for all group comparisons), but controls showed highest values, i.e. their extension MVC levels were higher than the flexion MVC levels (**Table 3**).

Discussion

This study examined maximum force capacity values of trunk muscles in healthy inactive subjects (C) and subjects with different training modalities (ST and ET). As expected, ST subjects showed highest MVC values for both flexion and extension direction. However, they were also the heaviest and thus had higher UBW values than ET and C participants. There was no systematic difference in UBW and UBT between ET and C. As ST tended to be the smallest, the calculated UBT values did not show any differences between the groups. With the normalised maximum torque values (torque ratio) for extension, a systematic difference could only be proven for the comparison with C. Although the statistical level decreased from a 1 to 5% significance level, the systematic difference between ST and the other two groups remained detectable for flexion. For flexion and extension, no differences were found between ET and C for either the maximum torques or the torque ratios. No systematic differences were found for the ex/flex ratio.

Comparison of ST with ET and C

We expected ST to show the highest MVC values with a systematic difference compared to the other groups. The differences in trunk flexion values showed a significantly higher maximum strength capac-

Abstract

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Force capacity of trunk muscle extension and flexion in healthy inactive, endurance and strength-trained subjects—a pilot study

Abstract

Recreational sports are becoming increasingly important in overcoming the drawbacks of our modern sedentary lifestyle. We wanted to know whether ambitious strength or endurance training has a systematic effect on the maximum strength capacity of the trunk muscles compared to no sport at all. We investigated two groups of physically active men who practised either endurance (ET; cycling and triathlon, $n = 13$) or strength training (ST; power lifting, $n = 13$), and a group of healthy physically inactive men (control [C], $n = 12$). Training intensity was at competition level in both active groups. All participants performed isometric maximum voluntary contractions in flexion and extension direction. Independent of force direction maximum torque levels were highest for the ST group ($p < 0.001$ vs. ET and C), but after normalizing to the subject's upper body weight these differences decreased, together with a drop in significance levels (extension: $p < 0.01$ vs. C; flexion: $p < 0.05$ vs. ET; $p < 0.01$ vs. C). With respect to the ratio between extension and flexion maximum forces due to the small group size no systematic differences could be detected between the groups, but effect sizes imply relevant effects (ET vs. ST: $d = 0.588$, ST vs C: $d = -0.811$). The results of this pilot study indicate that ST show higher functional force capacity values for flexion compared to the other groups. For extension, ST and ET did not differ. These results imply relevant differences for the extension to flexion force ratio.

Keywords

Maximum force capacity · Trunk muscles · Healthy male subjects · Untrained · Specific training modalities

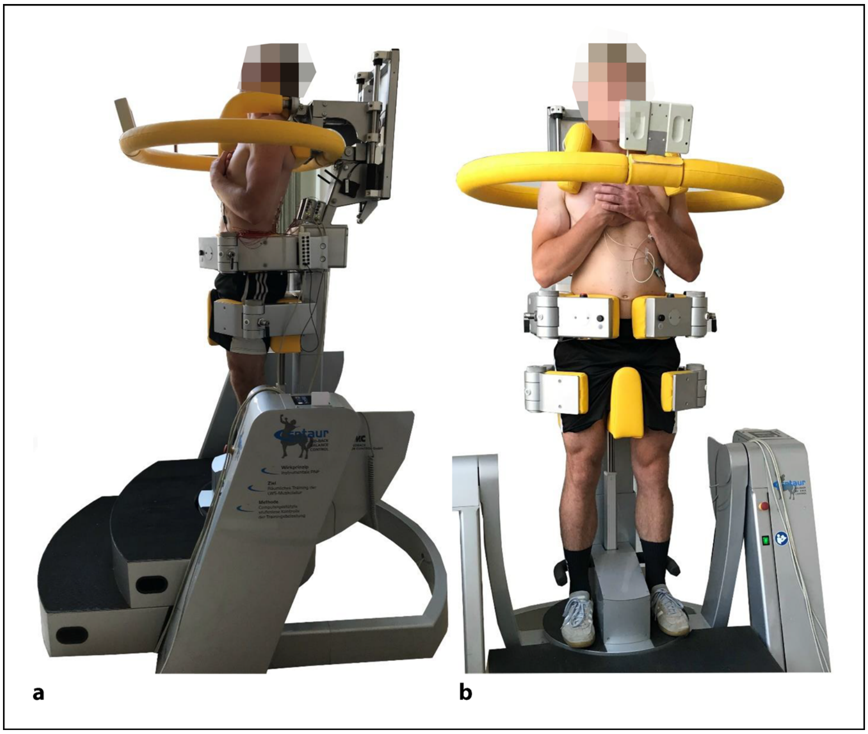

Fig. 1 ▲ Participant performing a maximum force extension task (leaning backwards): **a** sagittal view; **b** frontal view. Please note that the exercise is performed in upright position with the subject's lower body fixed and the upper body remaining free. Arms were always held crossed in front of the chest

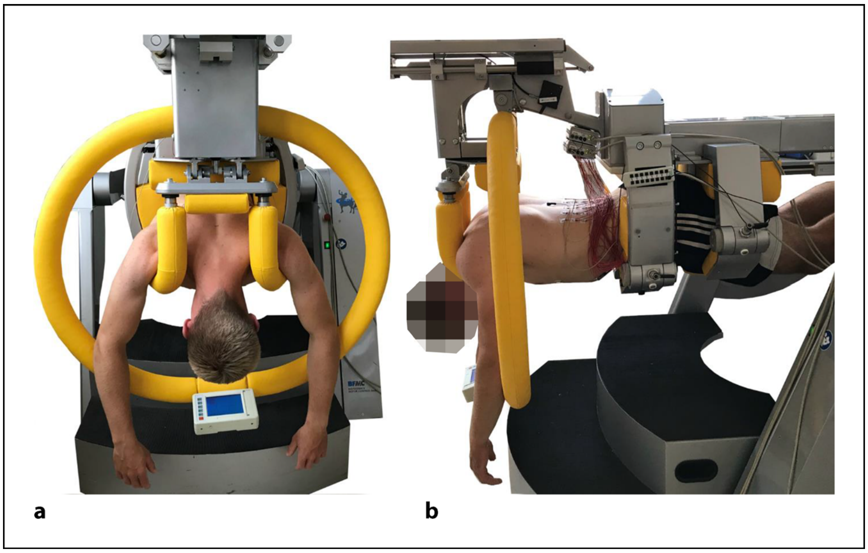

Fig. 2 ▲ Participant in horizontally tilted position to determine the upper body weight (UBW): **a** frontal view; **b** sagittal view

ity of the abdominal muscles for ST. This can be attributed to ST's training style, i.e. powerlifting. It consists of three exercises: deadlift, squat and bench press (Zatsiorsky, Kraemer, & Fry, 2020). The abdominal muscles play a crucial role in spinal stability by controlling intra-abdominal pressure and directly mediating tension through the thoracolumbar fascia (Cholewicki, Ivancic, & Radebold, 2002; Tesh, Dunn, & Evans, 1987; Yaprak, 2013). Each of the three exercises is associated with high intra-abdominal pressure during execution (Hackett & Chow, 2013; Harman, Frykman, Clagett, & Kraemer, 1988). This can also indirectly be deduced from the tendency of the lowest values for the ex/flex ratio for ST, which in this pilot study was not statistically detectable. This is in line with a study of strength athletes (wrestlers and weightlifters), where significantly lower ex/flex ratios compared to non-athletes were found (Zouita et al., 2019).

ET, on the other hand, do not specifically train their abdominal muscles and do not experience comparable maximum peak forces during their training that result in such increased intra-abdominal pressure. Therefore, they and C showed significantly lower maximum torque values of the abdominal muscles. This is in line with other studies, which were able to prove an abdominal weakness for endurance athletes (specifically triathletes), especially in trunk flexion (Ezechieli et al., 2013; Miltner, Siebert, Muller-Rath, & Kieffer, 2010). It can therefore be assumed that ST, due to their increased strength values of the abdominal muscles, show an increased stability of the spine compared to other training modalities.

The high extension torque values found in ST can also be explained by their training characteristics. In at least two exercises, powerlifting trains back muscles in addition to leg muscles while performing the task. A significantly increased maximum strength compared to C is therefore plausible. Although ST showed highest extension values, this difference disappeared when these values were normalised to UBW, at least for the comparison with ET. ET trained swimming, cycling and running, which require constant stabilisation of the spine (Villavicencio, Burneikiene, Hernandez, & Thramann, 2006), which is mediated by the paravertebral muscles and thus primarily extensors (McGill & Norman, 1986; Solomonow, Zhou, Harris, Lu, & Baratta, 1998).

This abolished difference in the torque ratio between ET and ST can be explained by significant differences in the UBW of both groups. ET had a significantly lower UBW than ST. ST showed higher absolute force values, but also had higher UBW values. The significantly lower maximum force values of ET are therefore levelled out by their lower UBW. The same applies to ST, where the high maximum

Table 2 Analysis of variance (ANOVA) results for outcome parameters

	UBW	UBS	UBT	MVC ex	MVC flex	Max. torque ex	Max. torque flex	Torque ratio ex	Torque ratio flex	Ex/flex ratio
f-value	6.407	6.035	2.827	13.351	18.099	6.591	10.854	4.517	12.362	2.827
p-value	0.004	0.006	0.073	< 0.001	< 0.001	0.004	< 0.001	0.018	< 0.001	0.073
pEta^2	0.257	0.246	0.133	0.419	0.495	0.263	0.370	0.196	0.401	0.133

Critical f-values: $p < 0.05$: 3.252; $p < 0.01$: 5.229

For description of UBW, UBS, UBT, MVC, maximum torque and torque ratio, please see Methods section

UBW upper body weight, *UBS* upper body segment, *UBT* upper body torque, *MVC* maximum voluntary contraction, *ex* extension, *flex* flexion, *pEta^2* partial Eta squared

Table 3 Outcome parameters per group. All values are displayed as mean values ± standard deviation (MV ± SD)

Group (*n*)	UBW (N)	UBS (cm)	UBT (Nm)	MVC ex (N)	MVC flex (N)	Maximum torque ex (Nm)	Maximum torque flex (Nm)	Torque ratio ex	Torque ratio flex	Ex/flex ratio
ET (13)	314.2 ± 27.7	39.1 ± 1.8	123.1 ± 12.3	768.8 ± 137.3	510.7 ± 99.4	300.1 ± 49.0	199.3 ± 36.6	2.45 ± 0.39	1.62 ± 0.24	1.52 ± 0.16
ST (13)	366.9 ± 44.7	36.4 ± 2.3	134.1 ± 21.8	970.9 ± 117.4	711.7 ± 129.8	354.8 ± 57.6	260.3 ± 55.5	2.66 ± 0.27	1.95 ± 0.32	1.40 ± 0.24
C (12)	324.4 ± 44.7	38.5 ± 2.2	125.1 ± 19.5	712.0 ± 142.8	446.0 ± 116.8	275.3 ± 61.9	172.9 ± 51.2	2.21 ± 0.44	1.37 ± 0.30	1.65 ± 0.38

For description of UBW, UBS, UBT, MVC, maximum torque and torque ratio, please see Methods section

ET endurance trained subjects, *ST* strength trained subjects, *C* inactive subjects/control group, *UBW* upper body weight, *UBS* upper body segment, *UBT* upper body torque, *MVC* maximum voluntary contraction, *ex* extension, *flex* flexion

force values are accompanied by also large UBW values. The normalised maximum torques of both groups are therefore not systematically distinguishable from each other. In one study that examined the muscular strength profiles of men of different ages (Viitasalo, Era, Leskinen, & Heikkinen, 1985), it was concluded that body mass index is an important variable to control for when studying differences in muscle strength. As we could show, the same applies to the control of the upper body weight.

Comparison of ET with C

As we expected ET to show higher MVC values for flexion and extension than C, it was somehow surprising that no significant difference between these groups could be proven, either in absolute or normalised values. As already mentioned, ET did not specifically train their abdominal muscles. Subjects of group C were inactive in sports and had a predominantly sedentary lifestyle. This was asked during the clinical history and inclusion criterion for this group. Consequently, their abdominal muscles were not trained at all. As ET's training behaviour does not require maximal peak forces during flexion, their musculature does not seem to be functionally and metabolically designed for maximum force production.

The back muscles of ET are, as already described, at least indirectly trained by their training and show similarly high force values as those of ST. Although C always had the lowest torque values, their average torque ratio value for extension was 2.2, which corresponds to a force reserve of well above 100% of their UBT value. These values correspond to the already published results of healthy individuals and can thus be considered representative (Kurz et al., 2014). C subjects seem to have some reserve for short-term maximum force production. Since the back muscles play a crucial role in mediating spinal stability in any everyday movement (Panjabi, 1992a, b; Ward et al., 2009), inactive individuals experience at least moderate loading of the back muscles. The maximum force production of moderately loaded (C) and indirectly trained (ET) muscles did not differ significantly, at least in our young aged population, although ET tended to have higher force values than C. It can be postulated that maximum force production is not significantly increased by endurance training.

The UBW values of ET and C did not differ significantly. The effects of UBW on the normalised torque values already described in 4.1 are not present in the comparison between ET and C.

Limitations

The current study bears some limitations which need to be addressed. ST most likely had an advantage in performing the MVC exercise. They are experienced through their training in extending their backs against resistance. ET and C might be at a disadvantage here. Also, in our study we only investigated the strength in sagittal direction. Therefore, investigations employing other directions of movement and functional aspects are needed for further questions, especially the effect of the strength reserve on everyday movements. Also, our results only included male subjects. Therefore, any transfer of these results to a female population has to be taken with caution. We applied a setup, which only contained the neutral trunk position (trunk angle 0°). Since previous studies were able to show a posture dependency for isometric trunk muscle force (Graves et al., 1990; T. S. Keller & Roy, 2002), our findings might differ if varying trunk angles were investigated.

In this study only a limited number of volunteers could be investigated. Nevertheless, this study could already provide basic information of training-associated changes in trunk muscle force production and thus forms the basis for further investigations in this field.

Table 4 Group-wise comparison of the respective data. Numbers are displayed as *p*-values with effect sizes (Cohen's d) together with their lower/upper borders for 95% confidence intervals

Group comparison	UBW	UBS	UBT	MVC ex	MVC flex	Maximum torque ex	Maximum torque flex	Torque ratio ex	Torque ratio flex	Ex/flex ratio
ET vs. ST	0.002 (−1.417: −2.28/−0.56)	0.003 (1.307: 0.46/2.15)	0.186 (−0.621: −1.41/0.17)	0.001 (−1.582: −2.46/−0.70)	< 0.001 (−1.739: −2.64/−0.84)	0.023 (−1.023: −1.84/−0.21)	0.004 (−1.298: −2.14/−0.45)	0.182 (−0.626: −1.41/0.16)	0.010 (−1.167: −2.00/−0.349)	0.207 (0.588: −0.20/1.37)
ET vs. C	0.744 (−0.277: −1.07/0.51)	0.631 (0.300: −0.49/1.09)	1.141 (−0.124: −0.91/0.66)	0.482 (0.406: −0.39/1.20)	0.222 (0.599: −0.20/1.40)	0.415 (0.446: −0.35/1.24)	0.224 (0.597: −0.20/1.40)	0.253 (0.579: −0.22/1.38)	0.054 (0.925: 0.10/1.75)	0.378 (−0.453: −1.25/0.34)
ST vs. C	0.039 (0.971: 0.14/1.80)	0.044 (−0.952: −1.78/−0.12)	0.428 (0.443: −0.35/1.24)	< 0.001 (2.032: 1.07/3.00)	< 0.001 (2.193: 1.20/3.19)	0.004 (1.360: 0.49/2.23)	0.001 (1.669: 0.76/5.58)	0.008 (1.272: 0.41/2.13)	< 0.001 (1.908: 0.96/2.85)	0.077 (−0.811: −1.63/0.01)

Please note that all values are presented after the Bonferroni correction. This allows them to be compared directly with the global significance level of 0.05

For definition of UBW, UBS, UBT, MVC, maximum torque and torque ratio, please see Methods section

ET endurance trained subjects, *ST* strength trained subjects, *C* inactive subjects/control group, *UBW* upper body weight, *UBS* upper body segment, *UBT* upper body torque, *MVC* maximum voluntary contraction, *ex* extension, *flex* flexion

Also, only young male subjects were investigated in this study. This was deliberately chosen to reduce variations due to expectable gender-related differences or also variations due to age-related changes.

Despite a larger number of evaluated variables, we have decided against the commonly used Bonferroni correction due to multiple testing. The aim of this study was mainly to give an illustration of the different meanings of different parameters (e.g. maximum force vs. normalized torque) that are used in practice. It is clear to us that the analysed parameters are not independent of each other, but in the practical application they are used alternately depending on the objective and thus independently of each other. In fact, each parameter in itself provides different information with respect to the particular question. A respective adjustment of the significance level across all parameters would not correspond to this evaluation or would complicate its interpretation in practical application.

Conclusion

It could be shown that effects on force capacity of trunk muscles differ between the training modalities strength training and endurance training, resulting in a higher force capacity for strength trained individuals. The results also indicate that inactive and endurance trained subjects have lower force values for flexion, compared to strength trained subjects. For extension, those values did not differ between the investigated training modalities, but between strength trained and inactive subjects. This leads to relevant differences for the ratio of extension to flexion forces. These results provide information about the training-induced change in force capacity of trunk muscles and should be investigated in further studies. Since we only investigated male subjects, a study with female subjects, who show similar training characteristics is recommendable. It would also be interesting to recruit and study similar subpopulations at an older age, as the musculature of older people should behave differently due to age-related changes.

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Declarations

Conflict of interest. T. Schönau and C. Anders declare that they have no competing interests.

All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the local ethics committee (2020–1844-BO). Informed consent was obtained from all individual participants included in the study.

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