Goran Marković[1], Damir Sekulić[2], Dražen Harasin[1] and Luka Šimić[1]

Gender differences in upper body explosive force production: effects of maximal strength and body size

Key words**: gender differences, explosive strength, muscle force, body size**
Ključne riječi: **spolne razlike, eksplozivna snaga, mišićna sila, tjelesna građa**

Original scientific paper

Abstract
This study analyzed gender differences in upper body explosive strength (1) before, and (2) after partialling out of the influence of fat free mass (FFM) and upper body maximal strength. Altogether 20 male and 21 female physical education students volunteered in this study. Maximal strength of the upper was assessed using one repetition maximum bench press test (1RM BP), while upper body explosive strength was assessed using seated ball (0.55 kg) or medicine ball (2 kg and 4 kg) throwing test, respectively. Throwing velocity was assessed using a radar gun. The results showed that men have significantly higher upper body explosive strength than women at all loading conditions, both before (~30%; $p < 0.001$) and after controlling for FFM (~10%; $p < 0.05$). When both FFM and upper body maximal strength (1RM BP) were controlled for, gender differences in upper body explosive strength disappeared ($p = 0.15$) only for the highest load applied (i.e. 4 kg). Taken together, our results suggest that gender differences in upper body explosive strength cannot be completely explained by gender differences in FFM. We conclude that other physiological factors should be looked for to explain size-independent gender differences in upper body explosive strength.

Sažetak
U ovom istraživanju analizirane su spolne razlike u eksplozivnoj snazi gornjeg dijela tijela (1) prije i (2) nakon parcijalizacije utjecaja nemasne mase tijela (FFM) te maksimalne snage gornjeg dijela tijela. Sveukupno 20 studenata i 21 studentica kineziologije dobrovoljno je sudjelovalo u istraživanju. Maksimalna snaga gornjeg dijela tijela procijenjena je potiskom s ravne klupe (1RM BP), dok je eksplozivna snaga gornjeg dijela tijela procijenjena bacanjem lopte (0.55 kg), odnosno medicinke (2 kg i 4 kg) iz sjedećeg položaja. Brzina lopte/medicinke mjerena je radarom. Rezultati su pokazali kako muškarci imaju značajno veću eksplozivnu snagu gornjeg dijela tijela od žena pri svim primjenjenim opterećenjima, i to prije (~30%; $p < 0.001$) i nakon parcijalizacije FFM (~10%; $p < 0.05$). Kada je istovremeno parcijaliziran utjecaj FFM i maksimalne snage (1RM BP), spolne razlike u eksplozivnoj snazi gornjeg dijela tijela su nestale ($p = 0.15$) samo kod bacanja najvećeg opterećenja (4 kg). Zaključno, ovi rezultati sugeriraju kako spolne razlike u eksplozivnoj snazi gornjeg dijela tijela nije moguće u potpunosti objasniti spolnim razlikama u FFM. Potrebna su daljnja istraživanja kako bi utvrdila druge fiziološke čimbenike odgovorne za spolne razlike u eksplozivnoj snazi gornjeg dijela tijela nezavisnoj od FFM.

Introduction

Gender differences in the force production capability are studied for decades (Hill, 1925; Hoffman, Stauffer, & Jackson, 1979; Maud & Shultz, 1986; Mayhew & Salm, 1990). Both experimental findings (Hoffman, et al., 1979; Davies & Dalsky, 1997; Valkeinen, Ylinen, Mälkiä, Alen, & Häkkinen, 2002) and our practical experience suggest that male participants generate significantly greater absolute muscle force than female participants. However, when the results are expressed relative to body size or body composition (i.e. fat-free mass, FFM), gender-related differences in the force production capacity either decrease (Mayhew & Salm, 1990; Batterman & Birch, 1996; Winter, Brookes, & Hamley, 1991) or completely disappear (Hoffman, et al., 1979; Maud & Shultz, 1986). It should be however, pointed out that the majority of previous research studied gender-related differences in lower body muscle strength and power (Maud & Shultz, 1986; Davies & Dalsky, 1997; Batterman & Birch, 1996; Winter, et al., 1991; Doré, Martin, Ratel, Duché, Bedu, & Van Praagh, 2005; Ford, Detterline, Ho, & Cao, 2000; Mayhew, Hancock, Rollison, Ball, & Bowen, 2001; Pincivero, Gandaio, & Ito, 2003). In contrast, studies evaluating gender differences in upper body muscle strength and power are lacking (Hoffman, et al., 1979; Nindl, Mahar, Harman, & Patton, 1995; van der Tillar & Ettema, 2004), particularly if we exclude those performed on children and adolescents (Nindl, et al., 1995; Wood, Dixon, Grant, & Armstrong, 2004). Moreover, limited data have offered conflicting findings; while some authors (Hoffman, et al., 1979) reported gender differences in upper body strength regardless if the results are expressed in absolute or relative to body size (i.e. per kg of body mass or FFM) values, others (van den Tillar & Ettema, 2004) suggest that gender differences in upper body strength are based solely on differences in FFM. Apparently, more research is needed before we could reach a definitive conclusion regarding gender-related differences in upper body strength and power.

Apart from the previously briefly reviewed problem regarding general (population) gender-differences in some of the strength and power variables, such problem is even more interesting in athletes, knowing the high importance of strength and power in different sports. (Grgantov, Katić, & Janković, 2006; Grgantov, Katić, & Marelić, 2005; Čoh, Milanović, & Emberšić, 2002). Review of literature in this area (e.g. sport) also indicates that most previous studies focused on gender comparisons in maximal muscle strength. Although maximal strength represents a relevant motor quality of athletes (Marković, Mišigoj-Duraković, & Trninić, 2005), much greater relevance to successful performance in sports has an explosive strength (Newton & Kraemer,

[1] *Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia*
[2] *Faculty of Kinesiology, University of Split, Split, Croatia*

1994). Specifically, many sports include frequent performance of upper body explosive movements like throwing (e.g. basketball, handball) or punching a ball (e.g. volleyball) (Rogulj, Srhoj, Nazor, Srhoj, & Čavala, 2005; Srhoj, Marinović, & Rogulj, 2002). Surprisingly, until now, very few studies compared males and females in upper body explosive strength (van den Tillar & Ettema, 2004). Off course, one could argue that such differences need not to be studied since it is well known that male upper body explosive performance are far more superior to female performance. The results in "throwing" sport-disciplines like javelin, and/or discus throw support this theorem. However, from our point of view, there are few possible suppressors for such condition, which are not phylogenetically related to explosive strength. First, there is certain possibility that males are generally superior in specific motor knowledge of throwing, knowing to be highly important in performing all motor tests and manifestations (Katić, Grgantov, & Jurko, 2006; Miletić, Katić, & Maleš, 2004). In our study such possible side-effect was efficiently controlled (see Methods). Second, it is well known that the sport-selection favours male athletes, indefinitely allowing certain negative-discrimination of the women in all sports (e.g. menstrual cycle, and/or pregnancy; not to mention sexism in some countries when women in sports are considered). It probably allows superior selection of the high-performers in male population (Babić & Viskić-Štalec, 2002). Thus, we believe that gender difference in upper body explosive throwing performance deserves to be studied.

Another important issue in studying gender differences in upper body explosive throwing performance is related to the magnitude of the external load. Specifically, Hill's force-velocity curve (1938) predicts that maximal movement velocity (i.e. explosive movement performance) has a variable relationship with maximal strength (and consequently with body size), depending on the magnitude of the load being overcame (Schmidtbleicher, 1992). Specifically, with an increase in external load, the relationship between explosive movement performance and maximal strength also increases. Since (1) genders differ from each other in relative maximal strength (Mayhew & Salm, 1990; Batterham & Birch, 1996; Winter, et al., 1991) and (2) the relationship between maximal strength and body size is not linear (Marković & Jarić, 2004; Jarić, Mirkov, & Marković, 2005), it is reasonable to expect that possible gender differences in explosive strength while overcoming greater loads, besides FFM, could also be the result of gender differences in maximal strength (Mayhew, et al., 2001).

In order to address aforementioned problems, we performed a study with the main purpose of establishing gender-related differences in upper body explosive muscle strength. Specifically, this research attempts to answer the following questions: (1) are there any gender differences in absolute and relative (i.e. size independent) upper body explosive strength, (2) if these gender differences exist, are they related to the load that is being overcome, (3) are gender differences in upper body explosive strength the result of differences between genders in maximal strength. For this purpose, we compared relatively homogenous groups of physically active men and women in their ability to throw explosively objects (ball or medicine ball) of the same diameter but different mass (0.55 kg, 2 kg, 4 kg), both before and after partialling out the influence of FFM and upper body maximal strength. We hypothesized that: (1) gender differences in upper body strength are present both before and after controlling for FFM (2) gender differences in upper body explosive strength are load-independent (3) partialling out the influence of maximal strength together with FFM will cancel out gender differences in upper body explosive performance only when throwing the heaviest object.

Methods

Subjects

Altogether 20 male and 21 female physical education students participated in the study. They were of the same age (mean age 21.8 years; range 21-24 years) and had similar levels of physical activity, as assessed by KIHD Seven-day physical activity recall questionnaire (Sallis, et al., 1985). The subjects were familiar with the applied tests due to their regular semi-annual testing of physical abilities. None of them reported health problems or recent upper body injuries. All the subjects had at least one-year experience in weight training through participation in a regular academic curriculum, but none of them specifically trained upper body maximal or explosive strength. It can therefore, be assumed that the two groups belong to the same population of healthy and physically active young adults. In accordance to University Guidelines for the Use of Human Subjects, all measurement procedures and potential risks were verbally explained to each participant prior to obtaining written informed consent.

Testing procedures

Measurements were performed in two separate sessions. During the first session, the subjects were tested on anthropometry and one-repetition maximum (1RM) bench press (i.e. upper body maximal strength test). During the second session (two to three days later), the subjects performed seated ball or medicine ball throws (i.e. upper body explosive strength tests). Each testing session was preceded by a standard warm-up and stretching procedure.

Anthropometry

Body height and body mass were measured to the nearest 0.5 cm and 0.1 kg, respectively. Body fat percentage and fat mass (kg) was assessed by a hand-held BIA unit – Omron_BF 306 body fat monitor (Omron Matsusaka Co., Ltd). Validity and reliability of this instrument has been previously demonstrated (Lintsi, Kaarma & Kull, 2004). Finally, fat-free mass (FFM) was calculated as a difference between body mass and fat mass. We also measured several other anthropometric measures (e.g. arm length, chest girth), but they were not reported in the paper.

1 RM bench press

Upper body maximal strength was assesses using a well-known 1 RM bench press test (Marković & Jarić, 2004) (1RM BP). In brief, each subject lowered the bar to the chest and, thereafter, raised it until his elbows were fully extended. Before testing participant's 1RM squat, a number of warm-up trials were given as follows: 30% (8 repetitions), 50% (5-6 repetitions), 75% (3 repetitions), and 90% (1 repetition) of an estimated 1RM. Since each participant had at least one-year of experience of training with free weights, the approximate value of 1RM was known in advance. After 90% of 1RM, loads were increased using small plates (2.5 kg and 1.25 kg) until the 1RM was reached. The process of assessment of 1RM bench press generally required no more than 4-5 lifts in order to complete.

Seated ball/medicine ball throw

Upper body explosive strength was assessed using the well-known seated medicine ball test (Marković, 2006). The subject was in a seated position on a chair with the ball or medicine ball in both hands on the chest. He/she was instructed to throw the ball/medicine ball with the maximum velocity towards the specified direction. Each subject threw basket ball (BB; 0.55 kg), 2 kg medicine ball (MB2), and 4 kg medicine ball (MB4) in a randomised fashion. The objects were of the same diameter and only differed in mass. Maximum ball/medicine ball velocity (km · h^{-1}) was measured using a calibrated Professional Radar Gun (Stalker, Applied Concept Marketing, Inc. USA). We used a stationary Doppler radar (operating frequency of 35.1 GHz) that can measure speeds between 1 km · h^{-1} and 480 km · h^{-1} with an accuracy of ± 0.1 km · h^{-1}. The radar gun was attached to a 0.5 m high stand and positioned behind a net, approximately 3 meters from the subject. The radar gun was calibrated immediately prior to the sessions according to the instructions given in the User's Manual.

Statistical analysis

All the data were reported as means ± SD. Pearson's correlation coefficient *r* was used to calculate the relationship between 1RM BP, FFM, and explosive throwing performance tests. Gender differences in anthropometric and performance measures were determined by a one-way analysis of variance (ANOVA). Finally, gender differences in ball/medicine ball throwing speed, after controlling for a) FFM or b) FFM and 1RM BP were determined by an analysis of covariance (ANCOVA). Statistical significance was set at a level $p<0.05$.

Results

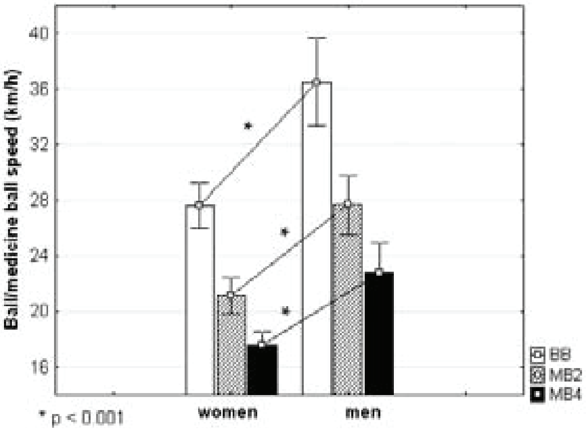
Descriptive statistics of all measured variables are reported in Table 1. As expected, men were taller, heavier and had lower body fat percentage compared to women ($F_{1,39}$ = 22.4-91.2; all $p<0.001$). Men also had significantly higher ($F_{1,39}$ = 83.7-144.5; all $p<0.001$) absolute upper body maximal and explosive strength than women (Table 1 and Figure 1). Note that the difference between men and women in the seated ball/medicine ball throw for all three loading conditions was relatively constant, between 30% and 32%.

Table 1.
Descriptive statistics of all anthropometric and strength measures for both men and women

	Men	Women
	Mean ± SD	
Body height (cm)	180.2 ± 6.2*	165.5 ± 4.2
Body mass (kg)	79.7 ± 12.4*	61.7 ± 5.2
Body fat (%)	9.9 ± 3.7*	16.7 ± 3.8
FFM (kg)	71.6 ± 8.9*	51.4 ± 3.7
1RM BP (kg)	89.9 ± 19.8*	47.5 ± 7.3
BB (km/h)	36.5 ± 3.2*	27.6 ± 1.6
MB2 (km/h)	27.7 ± 2.1*	21.1 ± 1.3
MB4 (km/h)	22.8 ± 2.2*	17.6 ± 0.9

Legend: FFM – fat free mass; 1RM BP – 1 RM bench press; BB – seated basket ball throw (0.55 kg); MB2 – seated 2 kg medicine ball throw; MB4 – seated 4 kg medicine ball throw; * significantly different values in men compared to women ($p < 0.001$).

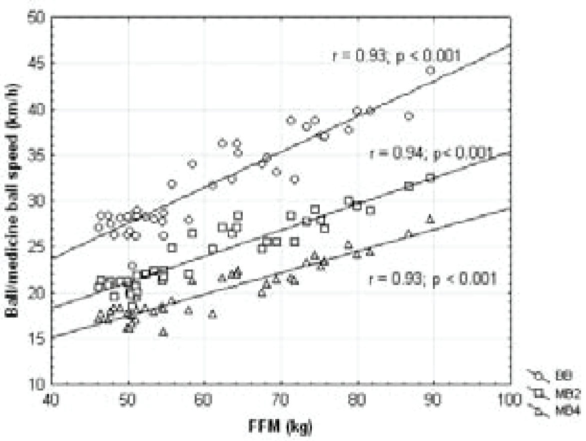
Figure 1.
Gender differences in upper body explosive strength for all three selected throwing tests.



Legend: BB – seated basket ball throw (0.55 kg); MB2 – seated 2 kg medicine ball throw; MB4 – seated 4 kg medicine ball throw

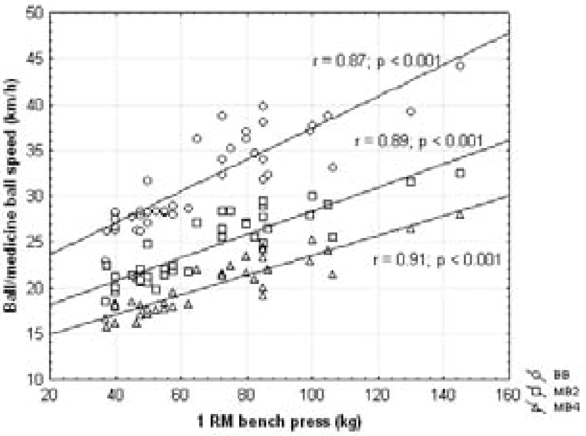
Figure 2 shows that there is a strong positive relationship between FFM and upper body explosive performance. In addition, we established a strong positive relationship between 1RM BP (i.e. upper body maximal strength test) and upper body explosive performance (Figure 3). Figure 3 also depicts that the relationship between maximal strength and throwing velocity increases as the load increases, in line with the prediction of the Hill's force-velocity curve. Finally, we observed that 1RM BP and FFM share about 75% of common variance (r = 0.87). These results support the use of both FFM and maximal strength, measured by means of 1RM BP, as covariates when analyzing gender differences in upper body explosive strength.

Figure 2.
Linear relationship between ball/medicine ball speed and fat-free mass (FFM) for all the subjects (n = 41)



Legend: BB – seated basket ball throw (0.55 kg); MB2 – seated 2 kg medicine ball throw; MB4 – seated 4 kg medicine ball throw

Figure 3.
Linear relationship between ball/medicine ball speed and 1 RM bench press for all the subjects (n = 41).



Legend: BB – seated basket ball throw (0.55 kg); MB2 – seated 2 kg medicine ball throw; MB4 – seated 4 kg medicine ball throw

After controlling for FFM, men still had significantly higher upper body explosive strength than women ($F_{1,38} = 5.6\text{-}15.7$; $p<0.05\text{-}0.01$), but these differences decreased to about 10%. Finally, when both FFM and 1RM BP were included as covariates, gender differences were cancelled out only in MB4 ($F_{1,37} = 2.0$; $p = 0.15$) where both covariates were highly significant (FFM; $F_{1,37} = 21.3$; $p<0.001$; 1RM BP; $F_{1,37} = 7.8$; $p = 0.008$). In case of two lighter loading conditions (i.e. BB and MB2), 1RM BP was not a significant covariate and thus, did not significantly contribute to a reduction of gender differences.

Discussion

In the present study we analyzed gender differences in absolute and relative upper body explosive strength. We also seek to understand possible effect of upper body maximal strength on these differences. Our results provided three groups of findings that are discussed in the following paragraphs.

Gender differences in absolute and relative upper body explosive strength
The main finding of our study is that men have significantly higher absolute and relative upper body explosive strength than women. This finding supports our first study hypothesis as well as most previous findings obtained in lower body explosive actions (e.g. sprints, jumps) (Maud & Shultz, 1986; Mayhew & Salm, 1990; Batterham & Birch, 1996; Cardinale & Stone, 2006). However, our results contradicts to the results recently reported by van den Tillar and Ettema (2004). Specifically, cited authors reported that gender differences in upper body explosive throwing performance (handball throw) are solely the results of gender differences in FFM. However, women in this study threw 20% lighter ball (360g vs. 450g) compared to men. Due to a well-known force-velocity relationship (Hill, 1938), we believe that these findings could be confounded by gender differences in mass of the ball being thrown.

In the present study we observed a very high relationship between upper body explosive performance and FFM (Fig. 2). Yet, partialling out the influence of FFM did not completely explain the observed gender differences in absolute upper body explosive strength. This finding together with previous observations (Maud & Shultz, 1986; Mayhew & Salm, 1990; Batterham & Birch, 1996, Cardinale & Stone, 2006) suggests that other physiological factors are responsible for size-independent gender differences in explosive strength. In our case, where the subjects performed explosive contraction against an external resistance, size independent gender differences could be the result of gender difference in percentage of the muscles within the upper body. For instance, it has been demonstrated that women have significantly smaller cross-sectional areas of upper body muscles compared to men (Janssen, Heymsfield, Wang, & Ross, 2000; Nindl, Scoville, Sheehan, Leone, & Mello, 2002). Therefore, a more appropriate body size descriptor for gender comparisons in upper body performance would be cross-sectional area of the upper body muscles.

Other qualitative factors that could contribute to upper body explosive strength differences between men and women include neurological and hormonal factors. Bell and Jacobs (1986) reported gender differences in electromechanical delay and in rate of force development. These factors are particularly important for single all-out explosive performance like jumping, kicking, and throwing (Newton & Kraemer, 1994).
Finally, the observed size-independent gender differences in upper body explosive strength could be the result of gender differences in blood concentrations of anabolic hormones. Recently, Cardinale and Stone (2006) reported significant positive relationship between testosterone levels and vertical jump height (i.e. lower body explosive strength) in elite men and women athletes. The cited authors also found significant differences between men and women in both testosterone levels and vertical jump height. Future studies should examine gender differences in upper body explosive strength while controlling for above mentioned physiological factors.

Effect of load on gender differences in upper body explosive strength
To our best knowledge, this is the first study that evaluated effect of various loading conditions on gender differences in upper body explosive strength. In line with our second hypothesis, the results clearly showed that gender differences in absolute upper body explosive performance are constant regardless of the external load applied. Specifically, men had about 30% greater throwing speed than women in all three loading conditions (i.e. 0.55 kg, 2 kg, and 4 kg). Similar finding is also observed in relative or size-independent upper body explosive strength where this gender difference was about 10% for all three loading conditions. The observed magnitude of gender differences in absolute and relative upper body explosive strength are also in agreement with some previous studies (Hoffman, et al., 1979). Taken together, these results suggest that gender differences in absolute upper body explosive throwing performance are independent of the external load applied, at least for loads ranging from 0.5 kg to 4 kg.

Effect of maximal strength on gender differences in relative upper body explosive strength
The third important finding of this study represents a significant effect of upper body maximal strength on gender difference in relative upper body explosive strength while overcoming the highest load applied (i.e. 4 kg). Specifically, we found that, when both FFM and 1RM BP were controlled for, gender difference in explosive throwing performance disappeared only in MB4, where both FFM and 1RM BP were significant covariates. In contrast,

there was no significant effect of 1RM BP on gender differences in explosive throwing performance while overcoming lower loads (0.55 kg and 2 kg). This finding can be explained by the Hill's classical force-velocity relationship. In particular, it is well known that the relationship between force production capability and movement velocity increases with an increase in the external load applied (Schmidtbleicher, 1992; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997). This is further supported by our data (see Figure 3), which show an increase in the relationship between upper body maximal strength and explosive throwing velocity. We are aware of only one study that evaluated possible effect of maximal strength on gender differences in explosive force production capability (Mayhew, et al., 2001). These authors found that maximal strength of leg extensor has a significant effect on gender difference in power generated during Wingate cycling test. Collectively, our results and the results of Mayhew and colleagues (2001) indicate that maximal muscle strength together with FFM may be responsible for gender differences in explosive force production capability, particularly when overcoming higher external loads. Future studies should test the validity of our results using lower body explosive strength tests like maximal sprints and jumps.

Conclusion

In conclusion, the results of this study showed that men have significantly higher absolute (č30%) and relative or size-independent (č10%) upper body explosive strength than women. These gender-related differences in upper body explosive strength are present when overcoming either low or moderate external loads ranging from 0.55 kg to 4 kg. When both FFM and upper body maximal strength (1RM BP) were controlled for, gender differences in upper body explosive strength disappeared only for the highest load applied. Taken together, our results suggest that gender differences in upper body explosive strength cannot be completely explained by gender differences in FFM, and that other physiological factors should be looked for to explain size-independent gender differences in upper body explosive strength.

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Correspodence to:
Goran Marković
Faculty of Kinesiology, University of Zagreb
Horvaćanski zavoj 15
10000 Zagreb, CROATIA
Phone: +385 1 3658606
E-mail: gmarkov@kif.hr