Assessment of Isokinetic Knee and Shoulder Strength in Elite Youth Boxers: Correlation with Punch Impact Force

Zixiang Zhou

Shanghai University of Sport

Xin Chen

Technical University of Munich

Chao Chen

Shanghai University of Sport

Wenjuan Yi

Shanghai University of Sport

Dexin Wang (✉ wangdexing@sus.edu.cn)

Shanghai University of Sport

Research Article

Keywords: isokinetic, punch, external rotation, extension

Posted Date: November 30th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1064025/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

This study aimed to assess the isokinetic strength performance of the knee and shoulder in amateur boxer, and further to explore the contribution of knee and shoulder peak torque to different punches. Boxers (6 females and 8 males) were measured the dynamic concentric torque of knee flexion(F) and extension(E), shoulder external rotation (ER) and internal rotation (IR) at 60°/S, 180°/S. We tested the punching force of three techniques by Kistler Instruments. At 60°/S, F/E ratios of the dominant (D) knee of female boxers were lower than those of non-dominant (ND) side ($p=0.03$). At two angular velocities, all boxers demonstrated higher ER/IR ratios in ND ($p=0.011$ for males, $p=0.025$ for females). Bilateral difference of knee flexor in females was greater ($p=0.038$) than that in males. The maximum correlation was found at 180°/S between punching forces and the joints strength. ANOVA analyses revealed that athletes with greater punching force tend to have higher knee strength. Although correlations between shoulders strength and punching forces were strong, they did not discriminate between athletes who punched with higher punching force. In order to effectively transfer muscle strength to punching force, rapid completion of action should be highlighted in strength training, especially lower-limb strength.

Introduction

Amateur boxing is an Olympic sport. To be the winner, boxers must deliver clear and powerful punches to score or knock down opponents. There are three punching techniques: straight, hook and uppercut, impact force of which is one of the vital performance indicators and the key factor to the victory of the competition 1,2. It was reported that the impact force was more elevated in elite boxers than in mediocre boxers and higher in the mediocre boxers than in novices 3. These studies showed that it was paramount for boxers to enhance their punching force, which was influenced by the muscle strength of upper and lower limbs. Therefore, it is necessary to explore the contribution of strength of knee and shoulder to punching force 4,5.

Isokinetic strength test, known as “gold standard” method, is a reliable and safe approach to measure the strength of muscles 6, to optimize the athletic performance and to prevent sports injury. It was reported that once the bilateral or ipsilateral limbs strength asymmetry exceeded a certain scope, not only the athletic performance would be negatively influenced but also the athletes 7, especially the young athletes whose skeleton and muscle systems are nevertheless immature, tended to suffer from muscle strain, anterior cruciate ligament (ACL) sprains and rupture 8,9. Many studies have examined the isokinetic strength characteristics of athletes in diverse sports 10-12. However, few studies have engaged in characteristics of isokinetic strength in boxers. Only one has assessed isokinetic strength characteristics of shoulder's rotators muscles of amateur boxer athletes by far 13, yet there is no report about the lower limbs' isokinetic strength characteristics. It's necessary to complement in this area of research.

During the last decade, there has been growing recognition of the significant association between muscle strength and sport performance 14. In fact, the correlation of muscle strength with sport performance has been studied in many sports, such as football 15, basketball 16, handball 11, water-polo 17. However, it is

known that there is no report about the correlation of boxers' upper and lower limbs peak muscle torque with punching force. Only one study described the relationship between punching force and muscular strength by countermovement bench throw and jump¹⁸. Previous study lacked the specific quantitative value on muscular strength. The aim of the present study, therefore, was to (1) analyze isokinetic strength characteristics of knee and shoulder of boxers (2) examine the relationship between the peak torque of knees and shoulders and the punching force of three techniques.

Methods

Participants

Fourteen (six females and eight males) young amateur boxers participated in the present study, with the average age 17.86 ± 0.9 years, height 171.21 ± 4.05 cm, weight of males 67.43 ± 4.42 kg, weight of females 60.35 ± 2.97 kg. All the players self-reported the right limb as their dominant limb. All participants were professional-level athletes and they have participated in national-level youth competitions. None of them have injured within six weeks before the test. At the beginning of the study, after they were informed the benefits and potential risks, they gave informed consent to participate. The study was approved by ethics committee of Shanghai University of Sport (102772021RT029) and in accordance with the Helsinki declaration.

Isokinetic Testing-knee

Isokinetic concentric torque of knee extensors and flexors was measured by an isokinetic dynamometer IsoMed2000 (Germany) at $60^\circ/\text{s}$ and $180^\circ/\text{s}$. According to the instruction manual for the IsoMed 2000 Systems, the participant was seated in appropriate and stable position using fixed straps to avoid compensatory trunk movement. The rotation axis of the machine and the knee joint were aligned, and the gravity compensation were performed. Before isokinetic test, each player performed a 15-20 minutes warm-up including stretching quadriceps, hamstrings, adductors, iliopsoas and gluteus. During continuous (bidirectional) knee flexion-extension movements the concentric isokinetic torque of the quadriceps and hamstrings was recorded at the angular velocities of $60^\circ/\text{s}$ and $180^\circ/\text{s}$, through a knee moving range from 0° (flexed) to 90° (full extension). Five maximal flexion and extension were performed at the two different angular velocities with 1-minute recovery between series. During the test, the participants must develop the maximum force at the same time during the two phases of extension and flexion. The test began with the dominant limb (D), then non-dominant limb (ND).

Isokinetic Testing-shoulder

Isokinetic concentric torque of shoulder external rotation (ER) and internal rotation (IR) was measured by an isokinetic dynamometer IsoMed 2000 (Germany) at $60^\circ/\text{s}$ and $180^\circ/\text{s}$. participants were seated with 45° of shoulder abduction in the scapular plane, which was regarded as reliable for external rotation and internal rotation strength assessment. The trunk and the hip were kept stable by two straps cross-placed in front of the chest and fixed to the back of the chair. The limb measurements began with the D side,

then ND. The length of the lever arm was adjusted for each participant, and each limb was weighed and used for gravity compensation. The maximal voluntary contraction of external rotation and internal rotation in angle of 60°/s and 180°/s was repeated five times with 1 minute of recovery between series.

Maximum punching forces

The equipment employed to assess the punching force was a force plate (Kistler Instruments, Winterthur, Switzerland) fixed on the tripod, with a built-in signal amplifier, and the sampling frequency sets at 1000Hz. Athletes were required to punch the target area in full force and then return to the starting position and keep stable and static. Each of three techniques of punches—Jab, Cross, Lead hook, Rear hook, Lead uppercut, Rear uppercut—were performed five times with a 15-second resting interval after each punch. Every technique of punches has a 1-minute resting interval. Due to different arm lengths, every participant was allowed to choose their own punching distance for their best performance. Verbal motivation was provided to each boxer to inspire the maximal punching force.

Peak torque of concentric contraction of knee and shoulder was expressed in absolute N and relative to body weight N/kg. The flexor to extensor(F/E) peak torque ratio was equal to dividing knee F concentric peak torque by knee E concentric peak torque. The external rotation to internal rotation (ER/IR) peak torque ratio was equal to dividing shoulder ER concentric peak torque by shoulder IR concentric peak torque. The BD% was the percentage difference between the peak torque of the D and ND, as follows: $BD\% = [(Higher\ PT - Lower\ PT) / Higher\ PT] \times 100$. Calculations were performed in Microsoft Excel.

Statistical analysis

All statistical analyses were performed using PRISM (GraphPad Software, Inc. Version 9.0.2 for Windows) and IBM SPSS Statistics (version 23). Descriptive statistics (means and standard deviations) were performed to summarize all data. The Shapiro-Wilk test for data normality was applied. Pearson or Spearman correlation analysis was employed to determine the relationship between maximal punching forces of three techniques of punches and shoulder IR and knee extensor peak torque of the participants. To exclude the impact of weight, all the comparisons mentioned in the article were relative quantities. As the qualitative evaluation of the degree of relationship, $r=0$ was considered null, between 0 and 0.3 weak, 0.3 and 0.6 moderate, 0.6 and 0.9 strong, 0.9 and 1 very strong, and 1 full¹⁹. Differences between genders and bilateral limbs were analyzed by unpaired two-tailed *t*-test with Welch correction when normality or equal variance of samples failed. When equal or normality was satisfied, the difference was analyzed using unpaired two-tailed *t*-test. **P* value less than 0.05 was considered significant; ***P* less than 0.01 was considered extremely significant.

The participants were divided into three groups according to their maximal punching forces; lower-level group (LG), medium-level group (MG), and higher-level group (HG), respectively. The first group contained 4 boxers (95% CI = 1822-2038 N), the second group contained 5 boxers (95% CI = 2179-2301 N), and the third group contained 5 boxers (95% CI = 2374-2656 N). Two-way ANOVA 3 (group) × 4 (joint) was used to test for differences in joints strength at two velocities between three groups. Post hoc analysis was

conducted using Fisher's least significant difference (LSD) test. For all statistical tests, significant wans $P \leq 0.05$. The Levene method was used to test the homogeneity of variance. Effect sizes (ES) were calculates using cohen's d : 0.25 is trivial, $0.25-0.50$ is small, $0.50-1.0$ is moderate, and $.1.0$ is large²⁰.

Results

The knee relative flexors to extensors peak torque (F/E) ratio was illustrated in Table 1 and Figure 1. At $60^\circ/\text{S}$ and $180^\circ/\text{S}$, F/E ratios ranged respectively $0.61-0.63$ for males and $0.58-0.63$ for females. At $60^\circ/\text{S}$, The F/E ratios of D knee in female were lower than those of ND side ($p=0.03$) and lower than that in males ($p=0.006$). The ratio of relative shoulder ER/IR peak torque was shown in Table 2 and Figure 1. At $60^\circ/\text{S}$ and $180^\circ/\text{S}$, ER/IR ratios ranged respectively $0.65-0.67$ for males and $0.66-0.70$ for females. At $60^\circ/\text{S}$, ND showed greater ($p=0.011$ for males, $p=0.025$ for females) ER/IR ratio than D regardless of sex. At $180^\circ/\text{S}$, ER/IR ratio in the ND showed gender differences that the ER/IR ratios from female were significantly higher ($p=0.021$) than those from the male. BD% values from extensor and flexor, IR and ER at two angular velocity were presented in Figure 2. The female athletes demonstrated greater BD% in flexor when compared to males 9.45 ± 1.72 VS 7.61 ± 1.25 ; $p=0.038$ at $180^\circ/\text{S}$. The absolute and relative values of punching force in Jab, Cross, LH, RH, LU, RU were shown in Table 3. Figure 3 shows the relationship between relative punching forces (RPF) and relative peak torque (RPT). The RPF of Jab had the greatest association with the RPT of D knee at 180° and indicated regular degree $r=0.536$, $p=0.031$. Likewise, correlations between Cross RPF and the RPT of D knee at 180° were greatest, belonging to strong relevance $r=0.603$, $p=0.007$. The RPF of LH and LU exhibited moderate levels of associated with the RPT of ND shoulder at 180° ($r=0.535$, $p=0.035$ and $r=0.572$, $p=0.029$, respectively). The RPF of RH and RU was greatly associated with the RPT of D shoulder at 180° , which lay in strong and moderate correlation ($r=0.663$, $p=0.006$ and $r=0.574$, $p=0.027$, respectively).

Results of the joints strength and punching force characteristics analysis are shown in Table 4. The ANOVA revealed that, compared with LG, knee $60^\circ/\text{S}$ was significantly higher in MG ($p=0.002$, $d=1.27$, $\text{CI}=0.94-1.59$) and HG ($p \leq 0.001$, $d=1.64$, $\text{CI}=1.07-2.20$), and HG was also greater than MG ($p=0.004$, $d=1.26$, $\text{CI}=0.91-1.61$). At knee $180^\circ/\text{S}$, HG was significantly higher than LG ($p \leq 0.001$, $d=1.37$, $\text{CI}=0.86-1.87$) and MG ($p=0.004$, $d=1.33$, $\text{CI}=0.71-1.95$), and MG was also greater than LG ($p=0.002$, $d=0.78$, $\text{CI}=0.41-1.15$). Compared with LG, shoulder $180^\circ/\text{S}$ was significantly higher in HG ($p=0.03$, $d=0.77$, $\text{CI}=0.35-1.18$). For punching variables, there was a main effect maximal punching force and relative punching force. Compared with LG, maximal punching force was significantly higher in MG ($p \leq 0.001$, $d=2.15$, $\text{CI}=1.24-3.09$) and HG ($p \leq 0.001$, $d=3.06$, $\text{CI}=1.57-4.54$), and HG was also greater than MG ($p \leq 0.001$, $d=2.23$, $\text{CI}=1.18-3.27$).

Discussion

The study focused on the Isokinetic strength profile of knee and shoulder young boxers. Based on this, we explored the relationship between peak muscle torques and punching force, which provide advice for coaches and athletics. The study found that: 1) at $180^\circ/\text{S}$ knee F/E ratio and shoulder ER/IR ratio were

higher than those values at 60°/S, and the gender difference appeared in F/E ratio of D at 60°/S and ER/IR of ND at 180°/S, 2) with the increase in angular velocity, the correlation coefficient between the punching force of three punching techniques and the RPT of knee extensor and shoulder IR was on a rise.

The F/E ratios of boxers increased with the increase in angular velocity. These results were in accordance with outcomes obtained in other sports 11·21. This may be due to the fact that flexor was characterized by relatively faster muscle fibers in comparison with extensor²². In low velocity movement, F/E ratio of D and ND limbs in female showed dramatic difference. This finding was contrary to previous studies on female basketball players which have suggested that there was no significant difference in D and ND 16. The difference between the results of studies may derive from the different modes of power generation in lower limbs. Boxing players prefer to firstly use the D limb to push off the ground, while basketball players jump with simultaneous two limbs pedal and stretch. Unfortunately, since there is no report about isokinetic strength in lower limbs of boxers, it is impossible compare the F/E ratio of knee among boxers.

It was reported that the normal value of knee F/E ratio was higher than 0.6 23, and if it is lower than 0.6, imbalance between the F and E will lower the stability and increase the risk of injury 17 times 24. In this study, F/E ratios in the D limb of female boxers were lower than 0.6 at 60°/S, and lower than those in males. These results seem to be consistent with other research which found that female players were more vulnerable to injury. It was reported that female athletes tended to suffer anterior cruciate ligament (ACL) injury 25. One reason for this may be weaker co-contraction of the flexor during knee extension, and stronger F may reduce overload imposed on the ACL 26. To increase the stability of knee and lower the risk of injury, it is necessary to correct the muscle imbalance of female boxer.

In the present study, ER/IR ratio exhibited lower values in the D regardless of gender, and ER/IR increased as the angular velocity did, which was consistent with previous research on boxer 13. Unfortunately, only male players have been included in previous study. After the female players were involved in present study, identical trends were found at two angular velocities. However, only at 180°/S, ER/IR ratios indicated striking sex difference. A possible explanation for this might be that as the angular velocity increased, IR muscles were capable of keeping stronger in males. For this reason, males ER/IR ratios were lower. In present study, only at 60°/S, ER/IR ratios showed significant difference within bilateral limb, while previous studies revealed this difference at both 60°/S and 180°/S 27. This inconsistency may be due to the difference in frequency of using two sides of the upper limbs. Previous study was based on volleyball spikers so that the use frequency of D limbs is higher than in ND limbs. But boxers showed similar frequency in use of D and ND limbs.

The value of ER/IR can be used to assess the shoulder dynamic stability. It was reported that ER/IR ratio ranged 0.66-0.75 could prevent the shoulder injuries 28. In our study, the ratio scope was 0.62-0.71. But there was no need to excessively worry about this ratio. Although boxing belongs to combat sports, shoulder strains/sprains happened in boxers was no more, or even lower than that in other sports, while cerebral concussion was the one to be prevented and avoided in boxing 29·30.

Female boxers demonstrated higher BD% in shoulder and knee than males. Nevertheless, only the BD% in knee flexor at 180°/S showed significant difference. Differences were not significant at other angular velocity and movement. In general, a 10–15% BD may be applied as a standard to stop athlete from exercise unless the balance recovers to normal range 31/32. Athletes with a BD% over 15% were 2.6 times more likely to get injured in weak limbs 33. In our research, only a few athletes demonstrated BD% higher than 10%, but lower than 15%. It is to be emphasized that the BD% will increase as the training experience does 34. Therefore, it is necessary to pay sustained attention to this indicator in order to prevent sport injury and training effects.

This study is the first to describe the relationship between the RPT of knee and shoulder at two angular velocities and the RPF of three punching techniques. It was found that correlation coefficients were higher at the 180°/S than at 60°/S. These relationships may partly be explained by the fact that the punching power is generated by fast muscle fibers, which also determine the power generated by high speed movement 35. As a result, punching force and the strength produced at 180°/S had stronger correlation. Many papers have also studied that the correlation between the explosive strength performance and peak torque in Isokinetic strength testing became greater as the angular velocity increased 16/36. In order to improve the punching force, plyometric training and complex training should be given more emphasis in training.

Jab, cross punching force was more positively correlated with the knee extensors peak torque, compared with shoulder IR. The explanation might be that because of the long distance to the target, boxers can fully extend their knee, and the extent of extension has strong correlation with power output 37/38. The extension of lower limbs would deliver power to upper limbs which accomplish the punching 39-41. we explained that the increase in muscle power of lower limbs would enhance the punching force from another viewpoint. The correlation coefficient between LH, LU, RH, RU and shoulder was greater, which may be related to other factors that influence the punching force, including extent of extension of knee and body rotation. Because hooks and uppercuts have shorter distance to the target, knee cannot extend fully. However, the contribution of knee strength is still large. This can be observed from three groups according to the punching force. HG showed greater knee strength compared with LG and MG. There results suggested the importance of lower-limb strength on punching force and it may be a key factor to generate higher punching force.

The present study first described the Isokinetic strength characteristics of knee and shoulder of boxers, and based on which the correlation between the strength of knee and shoulder and the force of three punches was determined. Former studies have reported the relationship between imbalance of knee strength and injury. In addition, athlete should emphasis speed of action in strength training, converting muscle power into punching force, especially lower-limb strength. We were aware of two major limitations in this study. First, the sample size was small. Second, athletes were free to choose their own punching time and distance in the impact force test, which was difficult to represent the real performance in practical competition. It was the limitation in the existing literature on punching performance of combat sport.

Conclusion

We suggested developing the strength of flexor to increase F/E ratios and to decrease BD% of knee, especially for females. RPF has stronger correlation with the RPT of knee and shoulder at 180°/S than at 60°/S. Therefore, athletics should emphasize the rapid completion of the movement in training exercise(e.g. plyometric training), which is favor to the transfer from muscle strength to punching force. Low-limbs strength should be paid more attention, because boxers with greater knee strength can produce higher punching force. Future studies about boxers need to focus more on punching performance in the formal competition, since knocking out the opponent is the ultimate goal of boxing.

Declarations

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgements

We would like to thank all the participants who volunteered for this study.

Funding

This work was partly supported by Shanghai Key Lab Human Performance. Award Number: 11DZ2261100

Author information

Affiliations

School of physical Education and Training, Shanghai University of Sport, Shanghai, China

Zixiang Zhou, Chao Chen, Wenjuan Yi, Dexin Wang

Department of Sport and Health Sciences, Technical University of Munich, Munich, Germany

Xin Chen

Shanghai Key Lab of Human Performance, Shanghai University of Sport, Shanghai, China

Chao Chen, Dexin Wang

Contributions

Z.Z. and D.W. designed the study and directed the project. Z.Z. and X.C. performed the laboratory analyses, the statistical analyses, and drafted the manuscript. C.C. and W.Y. performed the test and recorded the data.

Corresponding author

Correspondence to Dexin Wang

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Z.Z. or D.W.

References

1. Pierce, J. D., Reinbold, K. A., Lyngard, B. C., Goldman, R. J. & Pastore, C. M. Direct Measurement of Punch Force During Six Professional Boxing Matches. *Journal of Quantitative Analysis in Sports* **2** (2007)
2. Hukkanen, E. & Häkkinen, K. Effects of Sparring Load on Reaction Speed and Punch Force During the Precompetition and Competition Periods in Boxing. *J Strength Cond Res*, **31**, 1563–1568 <https://doi.org/doi:10.1519/jsc.0000000000001885> (2017).
3. Smith, M. S., Dyson, R. J., Hale, T. & Janaway, L. Development of a boxing dynamometer and its punch force discrimination efficacy. *J Sports Sci*, **18**, 445–450 <https://doi.org/doi:10.1080/02640410050074377> (2000).
4. Lenetsky, S., Harris, N. & Brughelli, M. Assessment and Contributors of Punching Forces in Combat Sports Athletes. *Strength Cond J*, **35**, 1–7 (2013).
5. Chaabène, H. *et al.* Amateur boxing: physical and physiological attributes. *Sports Med*, **45**, 337–352 <https://doi.org/doi:10.1007/s40279-014-0274-7> (2015).
6. Mayer, F., Horstmann, T., Kranenberg, U., Röcker, K. & Dickhuth, H. H. Reproducibility of isokinetic peak torque and angle at peak torque in the shoulder joint. *Int J Sports Med*, **15** (Suppl 1), S26–31 <https://doi.org/doi:10.1055/s-2007-1021106> (1994).
7. Myer, G. D., Ford, K. R., Brent, J. L. & Hewett, T. E. An integrated approach to change the outcome part I: neuromuscular screening methods to identify high ACL injury risk athletes. *J Strength Cond Res*, **26**, 2265–2271 <https://doi.org/doi:10.1519/JSC.0b013e31825c2b8f> (2012).
8. Shanley, E. & Thigpen, C. Throwing injuries in the adolescent athlete. *Int J Sports Phys Ther*, **8**, 630–640 (2013).
9. Fousekis, K., Tsepis, E., Poulmedis, P., Athanasopoulos, S. & Vagenas, G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players.

- Br J Sports Med*, **45**, 709–714 <https://doi.org/doi:10.1136/bjsm.2010.077560> (2011).
10. Andrade Mdos, S. *et al.* Isokinetic hamstrings-to-quadriceps peak torque ratio: the influence of sport modality, gender, and angular velocity. *J Sports Sci*, **30**, 547–553 <https://doi.org/doi:10.1080/02640414.2011.644249> (2012).
 11. Xaverova, Z. *et al.* Isokinetic Strength Profile of Elite Female Handball Players. *J Hum Kinet*, **49**, 257–266 <https://doi.org/doi:10.1515/hukin-2015-0128> (2015).
 12. Mascarin, N. C. *et al.* Strength Training Using Elastic Bands: Improvement of Muscle Power and Throwing Performance in Young Female Handball Players. *J Sport Rehabil*, **26**, 245–252 <https://doi.org/doi:10.1123/jsr.2015-0153> (2017).
 13. Tasiopoulos, I. *et al.* Isokinetic Characteristics of Amateur Boxer Athletes. *Front Physiol*, **9**, 1597 <https://doi.org/doi:10.3389/fphys.2018.01597> (2018).
 14. Andersen, C. H. *et al.* Scapular muscle activity from selected strengthening exercises performed at low and high intensities. *J Strength Cond Res*, **26**, 2408–2416 <https://doi.org/doi:10.1519/JSC.0b013e31823f8d24> (2012).
 15. Saliba, L. & Hrysomallis, C. Isokinetic strength related to jumping but not kicking performance of Australian footballers. *J Sci Med Sport*, **4**, 336–347 [https://doi.org/doi:10.1016/s1440-2440\(01\)80042-6](https://doi.org/doi:10.1016/s1440-2440(01)80042-6) (2001).
 16. Rouis, M. *et al.* Assessment of isokinetic knee strength in elite young female basketball players: correlation with vertical jump. *J Sports Med Phys Fitness*, **55**, 1502–1508 (2015).
 17. Olivier, N. & Daussin, F. N. Relationships Between Isokinetic Shoulder Evaluation and Fitness Characteristics of Elite French Female Water-Polo Players. *J Hum Kinet*, **64**, 5–11 <https://doi.org/doi:10.1515/hukin-2017-0181> (2018).
 18. Dunn, E. C., Humberstone, C. E., Franchini, E., Iredale, K. F. & Blazeovich, A. J. Relationships Between Punch Impact Force and Upper- and Lower-Body Muscular Strength and Power in Highly Trained Amateur Boxers. *J Strength Cond Res*, <https://doi.org/doi:10.1519/jsc.0000000000003585> (2020).
 19. Hopkins, W. G. Measures of reliability in sports medicine and science. *Sports Med*, **30**, 1–15 <https://doi.org/doi:10.2165/00007256-200030010-00001> (2000).
 20. Rhea, M. R. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res*, **18**, 918–920 <https://doi.org/doi:10.1519/14403.1> (2004).
 21. Andrade, M. D. S. *et al.* Isokinetic hamstrings-to-quadriceps peak torque ratio: The influence of sport modality, gender, and angular velocity. *Journal of Sports Sciences*, **30**, 547–553 <https://doi.org/doi:10.1080/02640414.2011.644249> (2012).
 22. Garrett, W. E. Jr., Califf, J. C., Bassett, F. H. 3 & rd. Histochemical correlates of hamstring injuries. *Am J Sports Med*, **12**, 98–103 <https://doi.org/doi:10.1177/036354658401200202> (1984).
 23. Ruas, C. V., Minozzo, F., Pinto, M. D., Brown, L. E. & Pinto, R. S. Lower-Extremity Strength Ratios of Professional Soccer Players According to Field Position. *Journal of Strength and Conditioning Research*, **29**, 1220–1226 (2015).

24. Yeung, S. S., Suen, A. M. & Yeung, E. W. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *Br J Sports Med*, **43**, 589–594 <https://doi.org/doi:10.1136/bjsm.2008.056283> (2009).
25. Myer, G. D. *et al.* The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clin J Sport Med*, **19**, 3–8 <https://doi.org/doi:10.1097/JSM.0b013e318190bddd> (2009).
26. Draganich, L. F. & Vahey, J. W. An in vitro study of anterior cruciate ligament strain induced by quadriceps and hamstrings forces. *J Orthop Res*, **8**, 57–63 <https://doi.org/doi:10.1002/jor.1100080107> (1990).
27. Kim, D. K., Park, G., Kuo, L. T. & Park, W. H. Isokinetic Performance of Shoulder External and Internal Rotators of Professional Volleyball Athletes by Different Positions. *Sci Rep*, **10**, 8706 <https://doi.org/doi:10.1038/s41598-020-65630-9> (2020).
28. Ellenbecker, T. & Roetert, E. P. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport*, **6**, 63–70 [https://doi.org/doi:10.1016/s1440-2440\(03\)80009-9](https://doi.org/doi:10.1016/s1440-2440(03)80009-9) (2003).
29. Pappas, E. Boxing, wrestling, and martial arts related injuries treated in emergency departments in the United States, 2002-2005. *J Sports Sci Med*, **6**, 58–61 (2007).
30. Zazryn, T., Cameron, P. & McCrory, P. A prospective cohort study of injury in amateur and professional boxing. *Br J Sports Med*, **40**, 670–674 <https://doi.org/doi:10.1136/bjsm.2006.025924> (2006).
31. Ellenbecker, T. S. & Davies, G. J. The application of isokinetics in testing and rehabilitation of the shoulder complex. *J Athl Train*, **35**, 338–350 (2000).
32. Neeter, C. *et al.* Development of a strength test battery for evaluating leg muscle power after anterior cruciate ligament injury and reconstruction. *Knee Surg Sports Traumatol Arthrosc*, **14**, 571–580 <https://doi.org/doi:10.1007/s00167-006-0040-y> (2006).
33. Knapik, J. J., Bauman, C. L., Jones, B. H., Harris, J. M. & Vaughan, L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J Sports Med*, **19**, 76–81 <https://doi.org/doi:10.1177/036354659101900113> (1991).
34. Lisowska, A. M., Murawa, M. & Ogurkowska, M. Isokinetic assessment of knee joint muscles in shotokan karate kata athletes. *Archives of Budo*, **16**, 61–66 (2020).
35. Gregor, R. J., Edgerton, V. R., Perrine, J. J., Champion, D. S. & DeBus, C. Torque-velocity relationships and muscle fiber composition in elite female athletes. *J Appl Physiol Respir Environ Exerc Physiol*, **47**, 388–392 <https://doi.org/doi:10.1152/jappl.1979.47.2.388> (1979).
36. Śliwowski, R., Grygorowicz, M., Wieczorek, A. & Jadczyk, A. The relationship between jumping performance, isokinetic strength and dynamic postural control in elite youth soccer players. *J Sports Med Phys Fitness*, **58**, 1226–1233 <https://doi.org/doi:10.23736/s0022-4707.17.07289-9> (2018).
37. Harrison, B. *et al.* The relationship between isokinetic performance of hip and knee and jump performance in university rugby players. *Isokinet Exerc Sci*, **21**, 175–180 <https://doi.org/doi:10.3233/les-130496> (2013).

38. Booyesen, M. J., Gradidge, P. J. & Watson, E. The relationships of eccentric strength and power with dynamic balance in male footballers. *J Sports Sci*, **33**, 2157–2165
<https://doi.org/doi:10.1080/02640414.2015.1064152> (2015).

39. Loturco, I. *et al.* Strength and Power Qualities Are Highly Associated With Punching Impact in Elite Amateur Boxers. *J Strength Cond Res*, **30**, 109–116
<https://doi.org/doi:10.1519/jsc.0000000000001075> (2016).

40. Monteiro, L. Assessment and contributions of grappling and punching forces in combat sports athletes: implications for the development of strength and conditioning. *Revista De Artes Marciales Asiáticas*, **11**, 14 (2016).

41. Irineu Loturco, L. A. P. *P. Reis,1 Felipe Romano,2 Mateus Alves,2 Tom ´as T. Freitas,3 and Michael McGuigan* (Transference Effect of Short-Term Optimum Power Load Training on the Punching Impact of Elite Boxers, 2019). 1 Ronaldo Kobal,1 Victor Fernandes,1 Valter

Tables

Due to technical limitations, table 1,2,3,4 is only available as a download in the Supplemental Files section.

Figures

Figure 1

Scatter plot of knee F/E ratios–shoulder ER/IR ratios of D and ND limbs from boxing athletes at 60°/S and 180°/S. *Significant difference between D and ND, # significant difference between male and female.

Figure 2

Box and whisker presenting 5–95 percentile of bilateral difference in peak torque of F and E of the knee and in peak torque of ER and IR of the shoulder at 60°/S and 180°/S *higher than males.

Figure 3

The analysis of correlation plot between RPT and RPF at two angular velocities. Red: maximum correlation * $p \leq 0.05$ ** $p \leq 0.01$

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Table1.jpg](#)
- [Table2.jpg](#)
- [Table3.jpg](#)
- [Table4.jpg](#)