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Correlation of bilateral and ipsilateral strength ratios with balance in female taekwondo athletes

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ORIGINAL PAPER

Abstract

This study aimed to analyze preferred leg (PLs) and non-preferred leg (NPLs) isokinetic knee strength, lateral asymmetry ratios and to examine their correlation with static balance. Sixteen female taekwondo (TKD) athletes voluntarily participated in the study. Knee isokinetic extension (Ex) and flexion (Flx) strength were measured in concentric / concentric (Con / Con) contractions at angular velocities of 60°/s, 180°/s, and 240°/s. Ipsilateral hamstring / quadriceps (H/Q) and bilateral (H/H and Q /Q) ratios were calculated. Static balances were determined by taking the center of body pressure in X (COPX) and Y (COPY) axis. Paired sample *t*-test and Pearson correlation tests were used in statistical analysis. When the isokinetic knee strength was examined, it was found that 60°/s angular velocity parameter was significantly different in Flx phase while 180°/s and 240°/s angular velocities were found to be significantly different in Ex phase in favor of PLs. There was no significance in bilateral and ipsilateral strength ratios of all angular velocities. There was a significant correlation between 240°/s HQ and COPX in terms of ipsilateral asymmetry ratios whereas a significant correlation was found between 60°/s HH and COPX in terms of bilateral asymmetry ratios. It was found that there were differences in strength between PL and NPLs, but no asymmetry was observed. There was no high level of correlation between lateral asymmetry ratios and balance in female TKD practitioners.

Keywords: Combat sports; martial arts; taekwondo; lateral asymmetry; isokinetic knee strength; balance.

Correlación de las ratios de fuerza bilateral e ipsilateral con el equilibrio en atletas femeninas de taekwondo

Resumen

Este estudio tuvo como objetivo analizar la fuerza isocinética de la rodilla de la pierna dominante (PL) y no dominante (NPL), las ratios de asimetría lateral y examinar su correlación con el equilibrio estático. Dieciséis mujeres atletas de taekwondo (TKD) participaron voluntariamente en el estudio. La fuerza de extensión (Ex) y flexión (Flx) isocinética de la rodilla se midieron en contracciones concéntricas/concéntricas (Con/Con) a velocidades angulares de 60°/s, 180°/s y 240°/s. Se calcularon las ratios ipsilaterales (H/Q) y bilaterales (H/H y Q/Q) isquiotibiales / cuádriceps. Los equilibrios estáticos se determinaron tomando el centro de presión corporal en los ejes X (COPX) e Y (COPY). El análisis estadístico se realizó mediante *t*-test de muestras pareadas y las tests de correlación de Pearson. Cuando se examinó la fuerza isocinética de la rodilla, se encontró que el parámetro de velocidad angular de 60°/s era significativamente diferente en la fase de Flx, mientras que las velocidades angulares de 180°/s y 240°/s eran significativamente diferentes en la fase de Ex a favor de las PLs. No hubo

Correlação de rácios da força bilateral e ipsilateral com equilíbrio em mulheres atletas de taekwondo

Resumo

Este estudo teve como objetivo analisar a força isocinética do joelho da perna preferida (PLs) e da perna não preferida (NPLs), as razões de assimetria lateral e examinar a sua correlação com o equilíbrio estático. Dezesseis mulheres atletas de taekwondo (TKD) participaram voluntariamente no estudo. A força de extensão (Ex) e flexão (Flx) isocinética do joelho foram medidas em contrações concêntricas / concêntricas (Con/Con) em velocidades angulares de 60°/s, 180°/s e 240°/s. Foram calculadas as rácios isquiotibiais / quadríceps ipsilaterais (H/Q) e bilaterais (H/H e Q/Q). Os equilíbrios estáticos foram determinados tomando o centro de pressão corporal nos eixos X (COPX) e Y (COPY). O teste *t* de amostra emparelhada e os testes de correlação de *Pearson* foram usados na análise estatística. Quando a força isocinética do joelho foi examinada, verificou-se que o parâmetro de velocidade angular de 60°/s foi significativamente diferente na fase Flx, enquanto as velocidades angulares de 180°/s e 240°/s foram significativamente diferentes na fase Ex em favor de PLs.

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diferencias significativas en las ratios de fuerza bilateral e ipsilateral de todas las velocidades angulares. Hubo una correlación significativa entre HQ a 240°/s y COPX en términos de ratios de asimetría ipsilateral, y se encontró una correlación significativa entre HH a 60 °/s y COPX en términos de ratios de asimetría bilateral. Se encontró que había diferencias de fuerza entre las PL y NPL, pero no se observó asimetría. No se halló un alto nivel de correlación entre las ratios de asimetría lateral y el equilibrio en atletas femeninas de TKD.

Palabras clave: Deportes de combate; artes marciales; taekwondo; asimetría lateral; fuerza isocinética de la rodilla; equilibrio.

Não houve significância nas rácios de força bilateral e ipsilateral de todas as velocidades angulares. Houve uma correlação significativa entre HQ de 240°/s e COPX, em termos de rácios de assimetria ipsilateral, enquanto uma correlação significativa foi encontrada entre HH de 60°/s e COPX em termos de rácios de assimetria bilateral. Verificou-se que havia diferenças de força entre PL e NPLs, mas nenhuma assimetria foi observada. Não houve um alto nível de correlação entre as rácios de assimetria lateral e equilíbrio em mulheres praticantes de TKD.

Palavras-chave: Desportos de combate; artes marciais; taekwondo; assimetria lateral; força isocinética do joelho; equilíbrio.

1. Introduction

Taekwondo (TKD), which became an Olympic sport in the 2000 Sydney Olympics, is a Korean martial art that aims to improve the combat skills of armies and soldiers (Pieter &Heijmans, 2000). Since TKD became an Olympic sport and there is a significant number of international competitions; researchers conducted several studies on physiological, psychological and other characteristics of TKD (Bridge et al., 2011; Skelton et al.; 1991; Sotoodeh et al., 2012).

Researchers who examined the effects of TKD training on physical and physiological parameters reported that flexibility and muscle strength came forward, in particular (Fong & Ng, 2011; Cejudo et al., 2018). Studies have stated that lower extremity muscle strength and balance are of great importance in TKD, since the most important factor is fast kick (Casolino et al., 2012; Machado et al., 2010) and it was also stated that lower extremity strength is not important only in kicking strokes, but also in jumping and maintaining postural stability (Pieter & Pieter, 1995). In addition, the importance of the calf, knee extensors and flexors during jump kicks and shuffling footwork has been emphasized by researchers (Park & Seabourne, 1997). When examined from a kinematic perspective, it has been proven that the gastrocnemius and quadriceps (Q) muscles during kicks and the hamstring (H) muscles are intensely active in order to prevent knee hyperextension during kicking (Sorensen et. al., 1996). With these aspects, it is clearly seen that the importance of knee extension (Ex) and flexion (Flex) strengths in TKD is important for both applying the strength efficiently and maintaining the balance by maintaining postural stability. Just like strength, balance is one of the main components of TKD since it is essential to remain in balance while using techniques against the opponent and reacting against the attacks of the opponent (Kukkiwon, 2006). Furthermore, the ability to adjust the body weight into a motion without losing balance in the process of releasing the strength at the target point is important for the purpose of TKD competition (Korean Taekwondo Association (KTA), 2015; World Taekwondo Federation (WTF), 2015).

Although knee strength can be measured by different methods, it is known that the most valid and reliable measurements are made with isokinetic dynamometers (Brown, 2000). Thanks to isokinetic dynamometers, the strengths of the Q and H muscles in Ex and Flx phases, which constitute the main movement mechanism of the knee joint and have an agonist and antagonist relationship between each other, can be objectively determined (Ermiş et al., 2019). The strength ratios of the Q muscle during strength generation in the Ex phase and H muscles during the Flx phase also show us whether the TKD practitioners have a tendency towards injuries that may occur in the knee area (Maly et al., 2017). This ratio increases as the test speed increases in isokinetic dynamometers and is considered normal between 50-80% depending on the angular velocity in TKD and other martial arts; this ratio is in the normal reference range of 60% at 60°/s (Baroni et al., 2020; Ermiş et al., 2019; Machado et al., 2009; Kazemi and Pieter, 2004). Likewise, when the difference between the right and left knee Q and H muscle strengths is higher than 10-15% it indicates asymmetry, and when this ratio exceeds 20%, the risk of knee injury is very high (Ermiş et al., 2019; Kannus, 1994). When studies conducted on TKD and some of the other martial arts are examined, it can be seen they reported that depending on angular velocity, elite and sub-elite athletes with no history of lower extremity injury had H/Q ratios between 50 and 80%, this ratio increased as angular velocity increased, and that strength differences between the right and left sides were between 10 and 15% (Ermiş et al., 2019; Hammami et al., 2014; Kim et al., 2011; Machado et al., 2009; Kazemi & Pieter, 2004). In terms of

biomechanics variables, balance can be evaluated by the center of pressure (COP) movement when performing an individual motion. The COP is positioned within the base of support, and balance ability may appear differently depending on changes in position (Lugade et al., 2011). Although balance measurements applied to athletes are simple and easily applicable methods, in terms of evaluating postural stability and vestibular functions, conducting the measurements with devices which give clinical results such as isokinetic balance and vertical force platform tools is important for evaluating the results objectively; actually these methods are preferred in sport disciplines in which postural stability and vestibular functions are important such as TDK and other martial arts in terms of revealing the significance of balance factor (Fong et al., 2012; Fong & Ng, 2006; Perrin et al., 2002). Therefore, the lower extremities are considered to be one of the primary factors to keep the balance and optimum performance during training and competition and to assess the strength differences and asymmetries in TKD. Researchers stated that during the techniques applied in TKD, movement occurs functionally at different speeds and contractions and measurements made at low and high angular speeds can be associated with performance and predisposition to injury in isokinetic strength measurements. Hence, in studies conducted, lower extremity strength was focused on angular speeds of 60°/s and 240°/s (Fong et al., 2013; Kim et al., 2015).

The rate of injuries in both male and female TKD practitioners was reported to be higher than other full contact sports such as football, wrestling, and judo (Hootman et al., 2007; Lystad et al., 2009; Pieter et al., 2010). Furthermore, in a limited number of studies, it was reported that female TKD practitioners have lower disability tendencies compared to men (Pieter & Lufting, 1994; Beis et al., 2001). Since the number of studies conducted on female TKD practitioners is scarce, our current research becomes more valuable.

Considering all these aspects, the aim of our present study is to determine the Ex and Flx strengths generated by female elite level TKD practitioners in the preferred leg (PLs) and nonpreferred leg (NPLs) knees, and to reveal relationships of bilateral and ipsilateral strength ratios with balance. Our study hypothesized that the subjects would not reveal lateral asymmetry and that there would be correlations between asymmetric ratios and balance.

2. Materials and methods

2.1. Experimental Design

The research was designed according to a randomized controlled single blind experiment design. The subjects visited the laboratory for a total of 4 times, including demonstration and 3 test measurements. The time between each visit was 24 h. At the first visit, test protocols in the study were introduced and pilot measurements of all tests were taken after the measurements of height, body weight and body mass index (BMI). Height, body weight and BMI measurements were measured with Gaia 359 Plus BodyPass analyzer. In other visits, random PLs and NPLs with isokinetic knee strength at angular velocities of 60°/s ,180°/s and 240°/s on the sides and center of pressure in X axis (COPX) and center of pressure in Y axis (COPY) static balance tests were applied by using the post-warming block randomization technique. Balance measurements were measured on both legs. The PLs side of all subjects were determined as the right side. In our study, step-up test was preferred to determine PLs. In the step-up test, subjects were asked to step onto a 20-cm-high step (Hoffmann et al.,1998). The leg used to perform the step-up movement was determined as PLs. Before the measurements, 10 min of general warm-up and 5 min of stretching exercises were performed for the lower extremities. All test measurements were made at the same time every day (12:00-14:00). The research was conducted in accordance with the Helsinki protocol (World Medical Association, 2013). Ethics committee approval of the study was obtained by the local ethics committee (E-95674917-108.99-1441-2020/12).

2.2. Participants

16 elite female TKD practitioners who participated in national and international competitions and who had at least five years of regular training history participated in the study voluntarily. In addition, all of the participants were in Turkey junior national team and they were staying in Turkey Olympics preparation centers (Table 1). GPower 3.1 program was used to determine the number of subjects. The power analysis test was conducted following a pilot

application which indicated that 13 subjects were sufficient (Effect size: 0.87, Actual power: 0.95); however, to increase the reliability of the study and decrease possible risks, the study was conducted with 16 subjects. The subjects were informed about the purpose of the research and a consent form was obtained. Exercise and high-intensity physical activities were not allowed before the tests. In addition, those who had previous knee injuries were excluded from the study. A separate nutrition program was not applied to the subjects. Subjects avoided alcohol and caffeine, during the 24 h prior to testing.

Table 1. Descriptive data of female taekwondo athletes (*n*=16).

Variable	Min.	Max.	M	SD
Age (years)	18.00	23.00	20.25	1.44
Height (cm)	161.00	180.00	167.81	5.34
Weight (kg)	53.00	69.00	60.31	4.92
BMI (kg/m^2)	19,47	23.14	21.40	6,25

2.3. Isokinetic Static Balance Test

Static balance tests were performed with ProkinTecnoBody isokinetic balance device (CSMI-TecnoBody PK-252, Dalmine, Italy). Static balance test was carried out on a fixed platform, standing on two legs with barefoot, with eyes open. During the test, the optimum position was determined so that the feet are shoulder-width open and the standing positions of the feet are at an equal distance to the origin point by referring to the lines on the X and Y axis of the platform. During the test, which lasted for a total of 30 s, the position was asked to be kept and the subject was allowed to follow their COP both X and Y axis position on the screen. The test results were followed on the screen on the device and the COPX and COPY values were recorded as a range (mm) (İnce et al., 2020). Static balance tests were applied to the subjects only once. During the tests, the subjects were told that they had to stay in balance between the midpoint of X and Y axis and they were warned that their tests would be considered invalid with any extra body motion and that their results would not be evaluated. No negative situations that could cause tests to be canceled were encountered during the tests. As a result of the static balance test, balance scores of the subjects were taken according to the pressure they applied to the X and Y axis and recorded in cm/s as COPX and COPY.

2.4. Knee isokinetic strength measurements

Isokinetic dynamometer (Humac Norm Testing and Rehabilitation System, CSMI, USA) was used to determine the isokinetic knee Ex and Flx strength values. Immediately after the general warm-up protocol, the seat, dynamometer, adapter and other settings of the dynamometer were adjusted according to the fixed protocol specified for knee Ex and Flx strength values. According to this protocol, the knee joint range of motion (ROM) of the subjects was brought to the 0-90^o position and the back support of the chair was adjusted to be 85^o (0^o = full extension). The dynamometer arm rotation was determined at the lateral femoral epicondyle level. The pad in which the lower leg attachment was fixed was adjusted to be proximal to the lateral malleus. Belts used to keep the body and the Q muscle from moving were tightened so that a gap of three fingers remained between the body and the Q muscle, and each subject held the hand grips on both sides of the seat during the test. During the test, each subject held the grips placed on both sides of the seat. In order to prevent movement of the contralateral limb, the ankle was placed in the leg stabilizer on the lower part of the chair. Prior to all tests, the rotation axis of the knee joint (lateral femoral condyle) and rotation axis were calibrated on the same line. In order to eliminate the effect of gravity, the torque value produced by the knee joint in 90^o extension, the leg in its free state and without applying force was determined with the dynamometer, and it was ensured that the resulting torque values after the measurements were only dependent on the strength. Before the tests, the subjects were asked to apply maximum knee strength to get the best results during the test. In order to ensure adaptation of the subjects and protect them from any injury, 3 trials were made before the test at each angular speed and a 30 second rest period was given. According to the fixed protocol of the dynamometer, 5 maximal repetitions for 60°/s and 180°/s and 15 maximal repetitions for 240°/s were performed. All tests were measured in concentric/concentric (Con/Con) contraction. Subjects were given 30 s of rest

between different measurements. Dominant side was measured first. In all tests, verbal warnings were made about the basic push-pull and remaining number of repetitions to warn the subjects to exhibit maximal performance. PT values obtained in all tests were recorded as Newton meters (Nm) (Yılmaz et al., 2019). H/Q ratio was automatically calculated by isokinetic dynamometer. Q/Q and H/H ratio were calculated with that formula ((NPLs Q/ PLs Q)*100) and ((NPLs H/ PLs H)*100) and they were recorded as percent (%).

2.5. Statistical analyses

SPSS 21.0 package program was used for the statistical analysis. Results were presented as mean and standard deviation. Shapiro-Wilk test was used to test normal distribution of the data. Levene's test was used to the test homogeneity. The paired sample t-test was used for the comparison of paired groups (PLs/NPLs' peak torque and H/Q) and Repeated Measures ANOVA test was used for the comparison of triple groups (Q/Q and H/H in all velocity). In the comparison of paired groups, effect sizes were found according to Cohen's d effect size (M2 - M1) /SD pooled). According to this formula, d <0.2 was defined as weak effect size, while d=0.5 was defined as moderate and d>0.8 was defined as strong effect size. Pearson's correlations test and Bonferroni correction were used to assess correlation between balance (COPX and COPY) and strength ratios (H/Q, Q/Q and H/H). p <0.05 was determined as statistically significant in paired and multiple groups. p<0.017 was determined as statistically significant in Pearson's correlation according to Bonferroni correction.

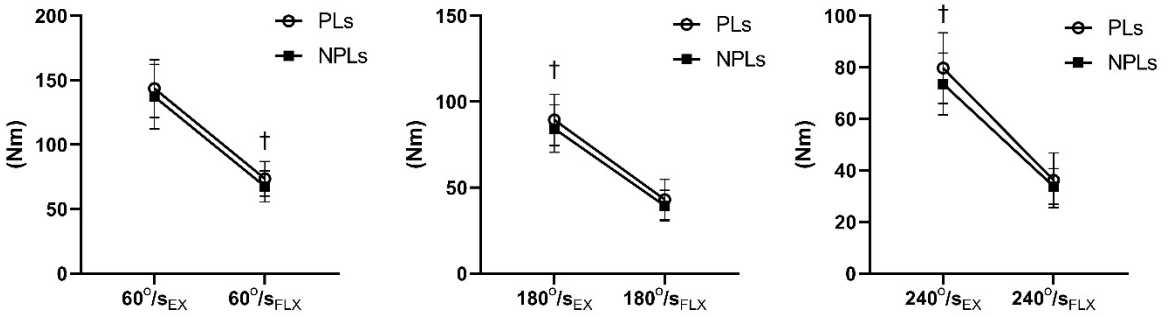
3. Results

Table 1 shows the static balance parameters (COPX and COPX) of the sujects, the strength values on PLs and NPLs they showed at 60°/s, 180°/s, and 240°/s angular velocities and bilateral and ipsilateral strength ratios. Comparison of the subjects' knee Ex and Flx strength values at 60°/s, 180°/s and 240°/s angular velocities between PLs and NPLs sides are presented in Figure 1. When the results found are evaluated, PLs and NPLs sides were found to show significant differences in favor of PLs side at 60º/s Flx (p = 0.042, 95% CI = 0.240-11.635, es = 0.46), 180°/s (p = 0.034, 95% CI = 0.427-7.380, es = 0.35) and 240°/s (p = 0.010, 95% CI = -1.392-6.142, es = 0.24) Ex phases (p<0.05) (Figure 1).

Table 2. Descriptive data of female taekwondo athletes (*n*=16).

Static Balance Parameters (cm/s)				
	Min.	**Max.**	**M**	**SD**
COPX (mm)	-9.00	3.00	1.81	2.34
COPY (mm)	-30.00	2.00	10.44	9.65
Isokinetic Knee Strength Parameters (Nm)				
		PLs (M±SD)	**NPLs (M±SD)**	
60º/s Ex (Nm)		143.56±22.40	137.25±25.06	
60º/s Flx (Nm)		73.50±13.47	67.56±12.06	
180º/s Ex (Nm)		89.44±14.88	84.37±13.83	
180º/s Flx (Nm)		43.00±11.80	39.44±9.03	
240º/s Ex (Nm)		79.69±13.68	73.56±12.02	
240º/s Flx (Nm)		36.18±10.56	33.81±6.9	
H/Q ratios (%)				
60º/s		51.25±7.63	50.00±6.52	
180º/s		48.18±9.53	47.50±5.64	
240º/s		45.31±9.43	46.69±7.48	
Q/Q and H/H ratios (%)				
		Q/Q (M±SD)	**H/H (M±SD)**	
60º/s		105.64±10.24	109±18.25	
180º/s		109.11±23.17	109.42±21.69	
240º/s		108±99±13.14	106.99±21.46	

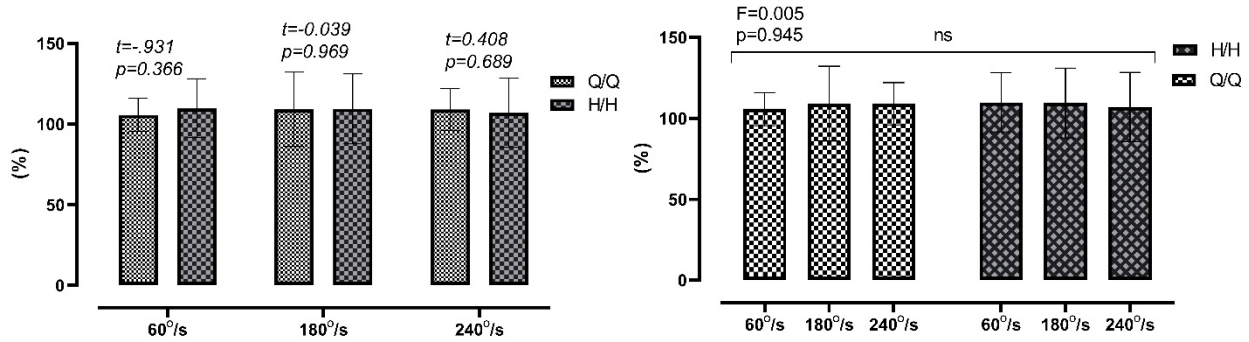
COPX. = Average centre of pressure in X axis; COPY. = Average centre of pressure in Y axis; Ex = extension; Flx = flexion; Q = quadriceps; H = hamstring; PLs = preferred side; NPLs = nonpreferred side.



† = p<0.05; PLs = preferred leg; NPLs = nonpreferred leg; EX = extension; FLX = flexion.

Figure 1. Peak muscle torque of knee extensors and flexors in PLs and NPLs extremities.

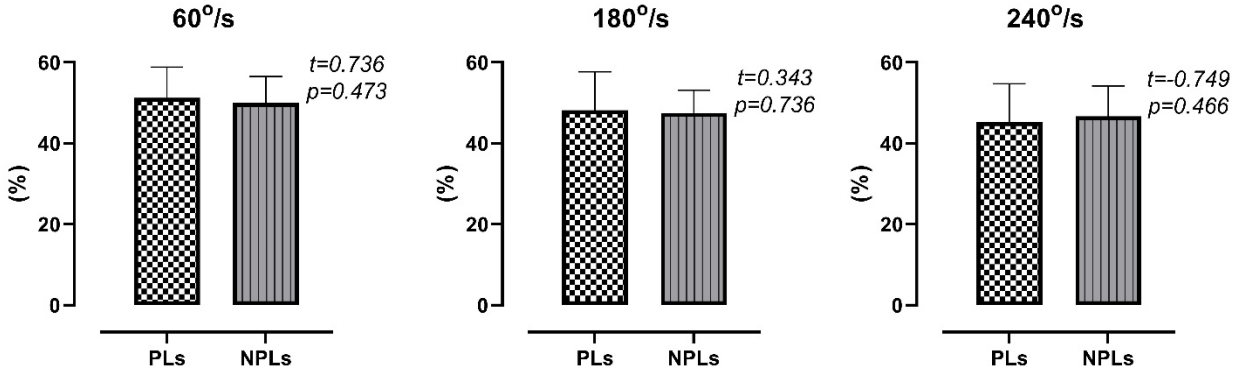
The comparisons of the subjects' bilateral strength ratios at 60°/s, 180°/s and 240°/s angular velocities are presented in Figure 2. There was no statistically significant difference when Q /Q and H/H were compared for both groups and between the same group for all angular velocities (p> 0.05) (Figure 2).



H/H = hamstring/hamstring; Q/Q = quadriceps/quadriceps; F = results of repeated measures ANOVA in all velocities between Q/Q and H/H.

Figure 2. Comparison of bilateral (Q/Q and H/H) ratio between peak muscle torque of knee extensors and flexors.

Comparison of the PLs and NPLs ipsilateral strength ratios of the subjects at 60°/s , 180°/s and 240°/s angular velocities are presented in Figure 3. According to the results, no statistical significance was found between the ipsilateral strength ratios of the PLs and NPLs sides (p> 0.05) (Figure 3).

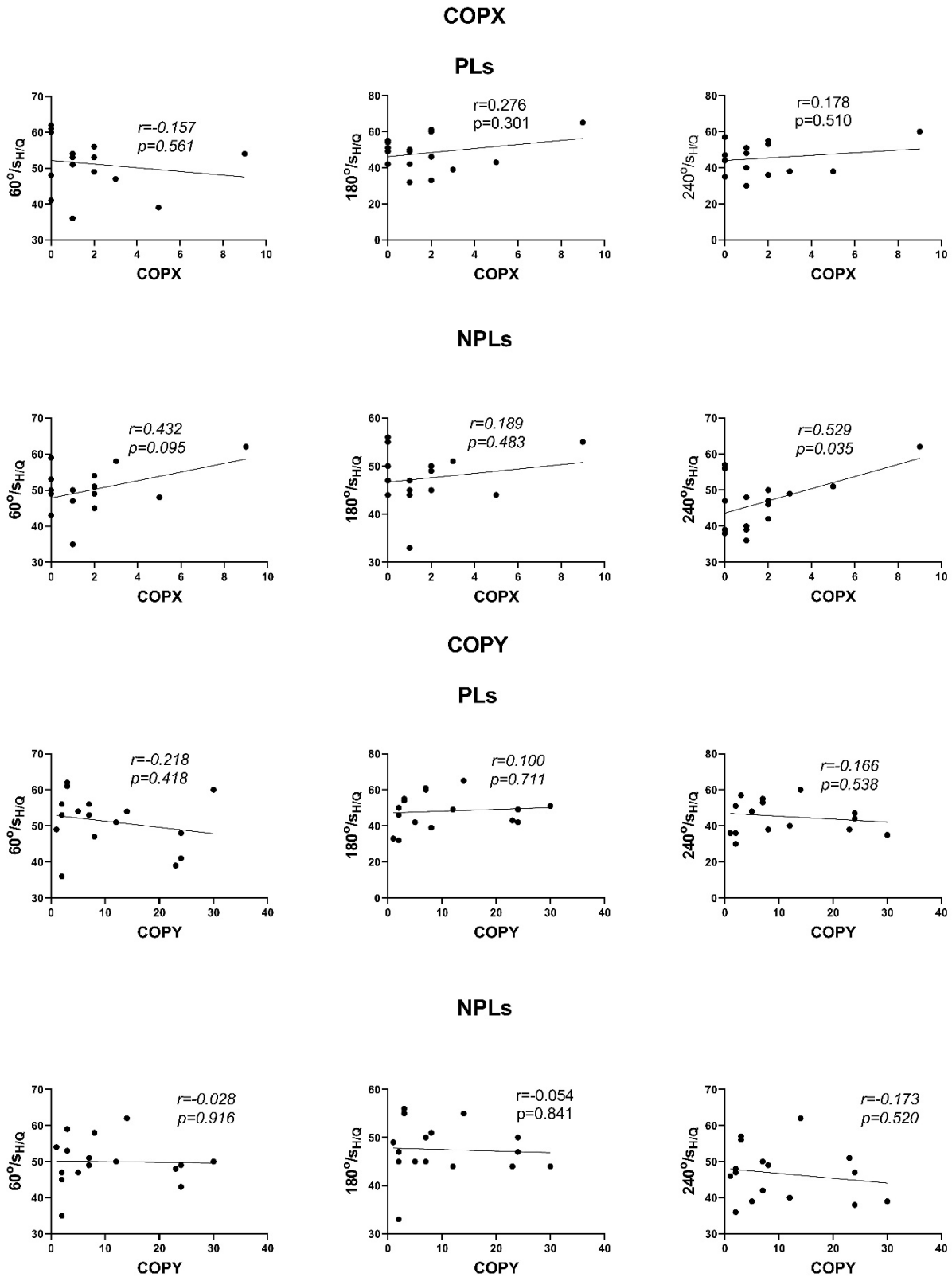


PLs = preferred leg; NPLs = nonpreferred leg.

Figure 3. Ipsilateral (H:Q) ratio between peak muscle torque of knee flexors and extensors.

In Figure 4, ipsilateral (H / Q) strength ratios at 60°/s, 180°/s and 240°/s angular velocities and correlations between COPX and COPY static balance parameters are presented. There were no

significant differences between H/Q and static balance parameters (COPX and COPY) in all velocities (p >0.017) (Figure 4).

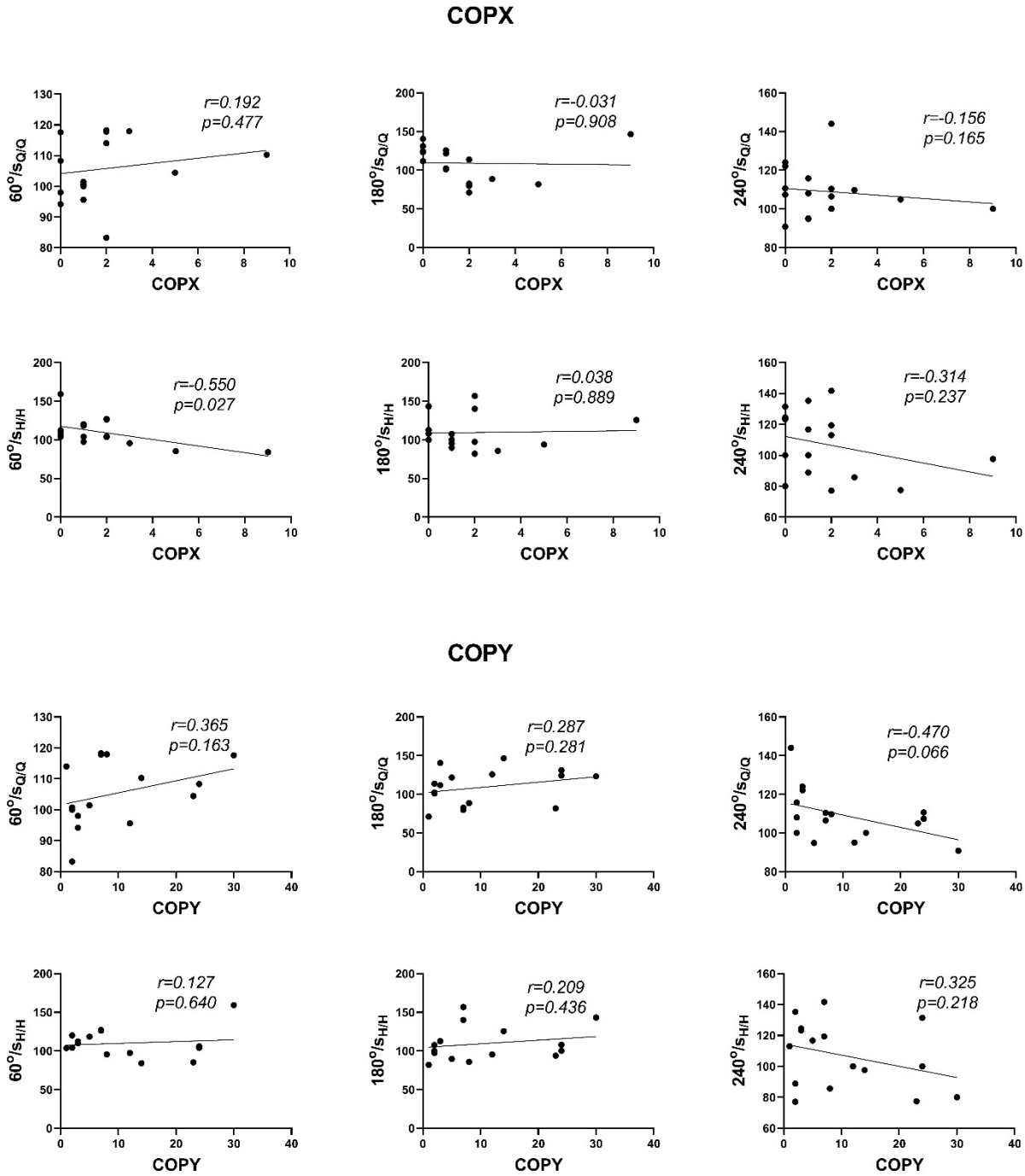


PLs = preferred leg; NPLs = nonpreferred leg; COPX. = Average center of pressure in X axis; COPY. = Average center of pressure in Y axis; H/Q = hamstring/quadriceps.

Figure 4. Correlation between ipsilateral strength ratios and static balance.

Figure 5 shows bilateral (H/H and Q/Q) strength ratios at 60°/s, 180°/s and 240°/s angular velocities and static balance parameters (COPX and COPY). There were no significant differences

between bilateral (H/H and Q/Q) strength ratios and static balance parameters (COPX and COPY) in all velocities (p >0.017) (Figure 5).



COPX. = Average center of pressure in X axis; COPY. = Average center of pressure in Y axis; H/H = hamstring/hamstring; Q/Q = quadriceps/quadriceps.

Figure 5. Correlation between bilateral strength ratios and static balance.

4. Discussion

Our current study investigating the relationship between bilateral and ipsilateral strength ratios calculated from isokinetic knee strength and static balance in elite female TKD practitioners revealed different major findings. These can be listed as follows; 60°/s angular velocity at Flx phase and 180°/s and 240°/s angular velocities at Ex phase revealed higher strength on PLs compared to NPLs. There were no significant correlations between strength ratios and static balance parameters (COPX and COPY). In addition, although significant differences were detected in isokinetic knee strengths at different angular velocities on the PLs and NPLs sides, there was no difference in bilateral and ipsilateral ratios.

Although there are studies investigating the isokinetic strengths of the knee in TKD practitioners, there are no studies investigating the relationship between bilateral and ipsilateral strength ratios and static balance. A high level of kick combination and a good balance is necessary to hit the right spot and win the game in TKD (Kim et al., 2011). Since it is known that the most active muscles during kick strokes are the gastrocnemius, Q and H muscles (Sorensen et al., 1996), knee extensor and flexor strengths are of great importance (Moreira et al., 2020). Kim et al. (2015) did not observe any significant difference between Ex and Flx values of the angular velocities of 60°/s and 180°/s, as well as the balances evaluated by the flamingo balance test, in the measurements performed on female TKD practitioners following 1-year regular TKD training. Fong et al. (2013) performed single-leg standing balance (SSD) test and observed positive and significant improvements in children's isokinetic knee strengths and their unilateral static balance following TKD training in children with developmental coordination disorders. In their study, Fong et al. (2013) observed improvements in unilateral balance, postural stabilization and knee joint positions of adolescent individuals who received TKD training for more than one year, but the difference was not statistically significant, although there was an improvement in isokinetic knee strength. The results of studies prove that TKD training improves lower extremity Q and H muscle strength and also contributes positively to lateral (X-axis) balance. In our current study, although no significant correlation was found between strength ratios and static balance, the results closest to significance between strength ratios and balance were in lateral axis (COPX). In addition, the absence of differences in bilateral and ipsilateral ratios in our current study indicates that our subjects can use their balance on the lateral axis well while using the PLs and NPLs sides during the competition or training. Studies conducted on TKD practitioners generally show that bilateral and ipsilateral strength ratios are similar (Jung et al., 2017; Kim et al., 2011; Szafrański et al., 2015). We can assert that TKD practitioners can use their balance well in terms of lateral axis. Although there are limited number of studies examining the relationship between lower extremity strength and balance in different martial arts, they have shown different results. In their study, Ghram et al. (2019) did not find significant differences between the isokinetic knee strengths of the right and left sides in judokas; however, in this study they found different significant results between knee and ankle strength with postural stabilization and balance. The most important of these results was positive associations between strength and postural stabilization in tests conducted without any fatigue, while it was found that postural stability and balance decreased significantly as fatigue increased. In their study, Maszczyk et al. (2018) examined whether neurofeedback developed balance and the results showed that neurofeedback developed balance and at the same time postural stabilization. When evaluated in this aspect, considering that the sudden and strong contractions that occur during the emergence of force are neurofeedback, it is thought that continuous stimulation of the muscles during fast and hard strokes applied especially in TKD affect balance positively. In addition, studies conducted have shown that there are no differences between PLs and NPLs of healthy martial art athletes with no history of injury in terms of lower extremity strength and that H/Q ratios are within normal norm ranges (Ermiş et al., 2019; Drid et al., 2015).

In their study on the effects of TKD training in female judo practitioners, Fong & Tsang (2012) indicated that especially 240°/s angular velocities had high correlations with Ex and Flx phases and TKD training durations, while no correlation was found in terms of 60°/s angular velocity. Since the contribution of rapid kicks is important to success in TKD, the correlations with high angular speed are expected, especially at 240°/s. Pieter & Pieter (1995) indicated that kick strokes were between 5.2-16.26 ms in elite TKD practitioners while O'Sullivan et al. revealed that the peak angular velocity of TKD practitioners was 1585.8°/s in turning kick and 926.1°/s in back kick, which are the most commonly used kicking techniques in TKD. When the results in our present study were evaluated, although no correlation was found between strength ratios and static balance, the results closes to significance were found especially between 240°/s at NPLs and COPX. It is thought that continually repeated fast and serial kicks of TKD practitioners during both training and competitions causes the balance to develop in balance foot NPLs and therefore significant correlations occur between them. We can assert that both these two findings and the findings of Fong & Tsang (2012) support our findings. Furthermore, it was observed that there were no significant differences in knee strengths at low angular velocities between the TKD practitioners and the control groups, but TKD groups had higher strength values as the angular velocity increased (Mendonça et al., 2007). This can be explained by the fact that fast twitch muscle fibers take a more active role than slow twitch fibers by

training Q and H muscles specific to the speed in TKD practitioners. Although studies show that basic motions specific to the TKD generally reveal higher correlations with high angular velocities, there are studies showing the relationship between some components of high strength ratios and low angular velocities. Seo et al. (2015) observed an increase in isokinetic knee strength and anaerobic capacity at an angular velocity of 60°/s with the 8-week training they applied to university-age male and female TKD practitioners. Moreira et al. (2020) examined the relationship between the isokinetic strengths of the knee and kinematic data of TKD practitioners, and reported that the angular velocity of 60°/s revealed higher and significant correlations compared to 240°/s in parameters such as preparation time of kick and kick time. This is also a clear indication that the Q and H muscles, which show slow but strong contraction during the pre-kick preparation period and the kick, can also be associated with success in TKD.

When the findings of our study are evaluated together with the literature findings, our study has several limitations. Balance measurements were performed only with static balance measurements and hip strength, which are important in TKD, were not included in the assessment. In addition, the fact that there were no correlations between balance and strength in our measurement results is due to the fact that while balance measurements are made on both feet, strength measurements are applied separately on PLs and NPLs sides. Applying balance to PLs and NPLs sides separately in future studies may cause the correlations between both parameters to be higher. In the current study, TKD practitioners were not divided into weight categories and their strength was not examined according to body weight ratios. In future studies, the association of hip and trunk strength with static and dynamic balance parameters in addition to knee isokinetic strength will contribute positively to the literature. Furthermore, in future studies including larger sample size, it is of great importance to separate the weight categories of TKD practitioners in order to reveal the relations between strength and balance.

5. Conclusions and practical applications

In conclusion, our current study shows that isokinetic knee strengths in PLs and NPLs reveal significant differences at 60°/s angular velocity in Ex phase, and 180°/s and 240°/s angular velocities in the Flx phase in elite female TKD practitioners. In TKD, where rapid kicks are of great importance, it is generally thought that the transfer from Ex phase to Flx phase as the angle increases is due to the increased strength of Q muscle group due to more active use of PLs side. Furthermore, although not statistically significant, the correlations between bilateral and ipsilateral strength ratios at different angular velocities and COPX show that knee strength is important in TKD, especially in movements made at lateral axis. The results revealed that there are no asymmetric strength differences between PLs and NPLs in female TKD practitioners who do not have any lower extremity injury history. Trainers and athletes can apply specific training models to balance the lower extremity strength against asymmetric differences that may arise by monitoring knee strength before and during the season. No correlations were found between static balance and strength, including balance factor, which is known to be important for TKD. Training programs in addition to strength training may cause performance to get more efficient and useful.

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