Proposed strategy for rehabilitation and conditioning by using isokinetic variables for knee muscles

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Isokinetic strength evaluation of muscle action in both (concentric-eccentric) contraction is an important comprehensive evaluation for rehabilitation and conditioning programs formed for athletes that highlights the training process. The study's main purpose was to identify strength deficits and bilateral imbalance between (agonists–antagonist) knee muscles accompanied by the hamstring injury to establish an isokinetic conditioning protocol. Research sample was one of the Egyptian national squash team (males under 19 years), who suffered from chronic strain in his left hamstring origin while at the preparatory phase for the world championship (Namibia 2014). The design of the study consisted of two stages using isokinetic system for all modes of contraction. First (5 weeks) of isometric rehabilitation, and second (5 weeks) of isokinetic training. The results revealed that final (H:Q) ratio calculated after applying the conditioning protocol for the dominant leg was (92.48%), and the injured non-dominant leg was (87.50%), compared to the initial measurement of (91.15%) and (67.68%) respectively. Therefore, imbalance and strength deficits between hamstring and quadriceps were highly improved, in addition to (19.82%) amelioration in the injured non-dominant leg strength balance and enhancement in all isokinetic variables tested. Accordingly, subject's technical performance was enhanced in the (SSET) test to reach maximal speed of (2.45 m.s-1) and endurance of (stage 9, run 2).

Key words: strength deficits, (H:Q) strength ratio, bilateral asymmetry, muscle imbalance

Introduction

Muscle strains in the hamstrings are one of most common sports injuries among athletes of many popular sports events, in which high speed sprinting and kicking are frequently performed (AHui et al., 2012). When the hamstrings act to extend the hip, muscle strains may occur during rapid alternations between concentric and eccentric contractions (Petersen and Holmich, 2005), it may also occur during a rapid knee extension if the hamstrings fail to generate effectively eccentric counteraction to decelerate the movement (Croisier et al., 2008). Same muscle conditions and rapid alternations between concentric and eccentric contractions are essential for squash players in most squash skills, which are performed in the front area of the court about (300-400) repetitions during the same match.

It has been agreed that all grades of strain injury leads to a proportion of strength loss. The severity of muscle strain injuries is categorized as Grade I: mild strain injury with minimum tear of the musculotendinous unit and minor loss of strength. Grade II: moderate strain injury with a partial tear of the musculotendinous unit and a significant loss of strength that results in significant functional limitations. Grade III: severe strain injury with a complete rupture of the musculotendinous unit and is associated with severe functional disability (Clanton and Coupe, 1998; Petersen and Holmich, 2005).

Early strength and conditioning professionals felt that performance would be diminished if not all the muscles of the athlete were developed proportionally. Many sports activities cause a strength increase in one muscle group without a concomitant increase in its antagonists, such as quadriceps of sprinters and internal shoulders rotators of throwers. As the prime movers for any movement become stronger, the antagonist is placed under increased stress as a joint stabilizer (Davies, 1985). Compensation strategies should thus be implemented aimed at eliminating, or at least limiting the degree of asymmetry, to avoid the negative consequences asymmetries can have upon the health of athletes on the long-term (Balague et al., 2001; Rosa et al., 2014).

Many risk factors including poor flexibility, strength imbalance, insufficient warm-up, and fatigue have been proposed as risk factors for hamstring strain injury. Basic science studies have established the connections between muscle strain and strain injury, muscle optimum length and muscle strain, and flexibility and muscle optimum length, which support poor flexibility and insufficient warm-up as risk factors for hamstring strain injury (Brockett et al., 2004; Ahui et al., 2012).

However, lower-limb strength indices have been investigated to monitor the performance of athletes, as well as the rehabilitation progress of injured players. Two of the most commonly evaluated among these are bilateral hamstring strength asymmetry and (H:Q) ratio. (H:Q) ratio or ipsilateral strength ratio of (agonists – antagonist) knee muscles has been used to examine the functional ability, knee joint stability, and muscle balance between hamstrings and quadriceps during velocity dependent movements (Aagaard et al., 1995; Orchard et al., 1997; Clanton and Coupe, 1998; Hewett et al., 1999; Dvir, 2004; Impellizzeri et al., 2007; Impellizzeri et al., 2008; Drid et al., 2009; Wong and Wong, 2009).

The concept of a certain ratio between contralateral limbs and joint (agonists –antagonist) muscles has been expanded in the medical, rehabilitation and conditioning literature. Some studies asserted that a difference greater than (10-15 %) in contralateral limb strength of the knee joint would predispose an athlete to injury (Wyatt and Edwards, 1981; Knapik et al., 1991; Kim et al., 2001; Aquino and Leme, 2006).

In a comparison between different sports (Roy et al., 2012) have found that two groups of field and court players demonstrated less than (15%) discrepancy between dominant and non-dominant leg muscle strength during isokinetic test and there was no significant difference between the two groups.

Researchers have advanced the concept of having a hamstring to quadriceps strength ratio of (40-60 %) to prevent injuries (Aquino and Leme, 2006). Elite squash, tennis and track athletes confirmed the accepted (H:Q) ratio of (60-80 %) when testing at (90°/s) for peak strength (Read and Bellamy, 1990). Conversely, other studies have noted additional ratios which vary from (20-200%) in healthy populations (Beam et al., 1982; Rabita et al., 2005; Roy et al., 2012).

Thus, it becomes important for the practitioner to know the value that should be determined and used for rehabilitation and preventive purposes when determining a specific value of strength ratios using isokinetic assessment and training.

Upon reviewing previous literature, researchers found various studies involving many sports activities. Including Australian football, American football, English rugby, basketball and soccer; in addition to some individual sports, such as track and field, water-skiing, cross-country skiing, downhill skiing, judo, cricket, tennis, and bull riding. However, there were relatively few insufficient studies regarding squash.

In view of the fact that (H:Q) ratio is the most frequently-used variable for evaluating function in both athletes and patients with various injuries and pathologies of the knee, the purpose of our study was to measure bilateral strength asymmetry and (H:Q) ratio. In addition to other isokinetic variables such as angle of peak torque, average work, and average power during flexion (Flex) and extension (Ext). To establish hamstring strain injury rehabilitation and conditioning protocol for squash athletes.

Methods

Participants

Egyptian national squash team (under 19 years) consists of six world ranked players. Performance variables were tested using squash-specific exercise test (SSET) (Vincent et al., 2013), starting stage was six as recommended by test instructions. Somatic and performance variables are displayed in (table 1).

Table 1: Somatic and performance variables for the Egyptian national squash team (males under 19 years).

Performance variables (SSET)			**Somatic variables** (N = 6)		
maximal speed ($m.s^{-1}$)	Duration Run No.	Stage No.	weight (Kg)	Height (cm)	Age (Month)
2.37	6	8	68	174	204
2.69	5	10	70	181	209
2.71	6	10	73	185	216
2.56	7	9	70	176	214
2.54	6	9	72	180	215
0	0	0	69	176	205
M			70.33	178.66	210.50
± SD			1.86	4.08	5.24

M, Mean; SD, standard deviation; ($m.s^{-1}$), maximal speed

The experiment was designed for one member of the team (gray shaded) who suffered from reoccurred strain injury in left hamstring muscle origin accompanied by low back and hamstring pain, which prevented him from performing basic training tasks. Performance measurements before rehabilitation process were unattainable due to subject's inability to finish the test. A written informed consent from the subject's parents was obtained following a brief detailed explanation about the aims, benefits, and risks involved with this investigation. With the freedom to withdraw from the study anytime.

Isokinetic measurements

Bilateral isokinetic (concentric-concentric) knee flexion and extension studies within the protocol of 90°/s (10 repetitions) were performed at the

Faculty of Physical Education laboratory, Helwan University, using the IsoMed 2000 dynamometer (D&R GmbH, Gewerbering, Ost, Hemau, Germany) with the knee attachment on. Orientation of the dynamometer was kept at 0°, tilt at 0°, and seat orientation at 0°. Tests were performed bilaterally in the seated position (hip flexion angle at 110°).The dominant limb was assumed to be the one spontaneously used to kick a ball (Spurrs et al., 2003).

Isokinetic measurements before rehabilitation process were unattainable due to subject's inability to finish the test. Therefore, a full range of movement test (90°:180°) was conducted after rehabilitation and conditioning protocols. Before testing procedure, the subject performed warm-up exercises and stretching of the lower extremities for (10 min). Next, the subject was seated with stabilization straps at the trunk, abdomen and thigh to prevent excessive joint movements. The resistance pad was placed 3 cm above the ankle joint.

Each set, the attachments of the dynamometer were readjusted accordingly so that the center of motion of the lever arm was aligned as accurately as possible with the slightly changing flexion-extension axis of the joint. The subject was instructed to hold seats' handles during all testing and training sessions, the results were analyzed after obtaining them directly from the device without gravitational correction.

Rehabilitation protocol

Isometric rehabilitation exercises were performed for (5) weeks, (3) sessions per week for both hamstring (H) and quadriceps (Q) muscles. At the beginning of each session, a warm-up was performed for lower extremity (10 min). The knee joint angles used varied from (60°) to full knee extension (180°), and the duration of static contraction was (8-15 s), with the exact time of static contraction as recovery time between each repetition (Rep), and (2-4 min) recovery time between sets (Set).

Table 2 Isometric rehabilitation protocol
and biomechanical variables (5 weeks - 3 sessions per week).

Week	Knee joint angle	Static contraction		Recovery time	
		Duration (s)	Rep (No.)	Set (min)	Rep (s)
First	60°-90°-120°-150°-full (Ext)	8-10	5-6	3-4	8-10
Second	60°-90°-120°-150°-full (Ext)	8-15	8-10	3-4	8-15
Third	60°-90°-120°-150°-full (Ext)	8-15	8-10	2-3	8-15
Forth	90°-120°-150°-full (Ext)	10-15	10-12	2-3	8-15
Fifth	90°-120°-150°-full (Ext)	12-15	10-12	2-3	12-15

Conditioning protocol

After clinical report and injury healing confirmation, Isokinetic exercises were performed for (5) weeks, (3) sessions per week for both quadriceps (Q) and hamstring (H) muscles. At the beginning of each session, a warm-up was performed for lower extremity (10 min). Followed by (4-6) sets (10-12) repetition of alternative concentric and eccentric modes of contraction through the defined full range of movement. The knee joint angles varied from (60°) to full knee extension (180°), and angular velocities varied from (120°/s) to (200°/s), with (2-3 min) recovery time between sets.

Table 3 isokinetic conditioning protocol using concentric (Con) and eccentric (Ecc) modes of contraction. (5 weeks/ 3 sessions per week).

Week	Range of motion Con and Ecc		Set (No.)	Rep (No.)	Rest (min)	Angular velocity (°/s)
First	(90° - 180°) Full range	Alternatively	4-6	10-12	3	120
Second	(90° - 180°) Full range		4-6	10-12	3	140
Third	(90° - 180°) Full range		4-6	10-12	3	140
Forth	(60 ° -180 °) Full range		4	10	2	160
Fifth	(60 ° -180 °) Full range		4	10	2	200

Results

After each test of isokinetic variables, statistical analysis (T-test, mean and standard deviation) were used to examine data. (H:Q) ratios were calculated and compared. (Table 4) shows isokinetic variables differences between left and right leg muscles measured before applying the conditioning protocol.

Table 4 Isokinetic variables differences between left and right leg muscles during (Flex) and (Ext) at the full range of movement (After rehabilitation).

Isokinetic variables (N=10)	Unit	Left		Right		T- test	MD
		M	± SD	M	± SD		
1. Angle of peak torque (Flex)	(°)	84.00	3.43	99.00	6.79	-5.68*	-15.00
2. Angle of peak torque (Ext)	(°)	124.00	4.02	138.00	7.81	-7.16*	-14.00
3. Peak torque (Flex)	(N·m)	67.00	2.10	103.00	3.36	-32.56*	-36.00
4. Peak torque (Ext)	(N·m)	99.00	6.39	113.00	2.78	-5.74*	-14.00
5. Work (Flex)	(J)	63.70	1.63	104.50	2.21	-45.61*	-40.80
6. Work (Ext)	(J)	100.50	3.85	109.50	1.15	-7.32*	-9.00
7. Power (Flex)	(w)	53.00	2.16	63.00	3.19	-22.36*	-10.00
8. Power (Ext)	(w)	61.00	4.44	68.00	2.40	-3.51*	-7.00
Total		**652.20**	**7.05**	**798.00**	**9.01**	**-41.25**	**-145.80**

M, mean; SD, standard deviation; MD, mean difference;* significance level (P < 0.05)

Differences in average of peak torque, average work and average power between left and right (H) muscles were (-36.00, -40.80, -10.00) compared to (Q) muscles (-14.00, -9.00, -7.00) respectively, while difference in peak torque angle between left and right (H)) muscles was (-15.00) in comparison to (-14.00) for (Q) muscles.

Although all isokinetic variables measured showed a significant differences (P < 0.05) between left and right leg muscles hence to the tendency of using the dominant side of the body, there was significantly greater difference between non-dominant leg (left) and dominant leg (right) in average of peak torque during (Flex) (67-103 N·m), and average work during (Flex) (63.7-104.5 J respectively), which could be explained as a result of hamstring strain injury.

Figure 1 Left to right muscles ratios during (Flex) and (Ext) at the full range of movement (After rehabilitation).

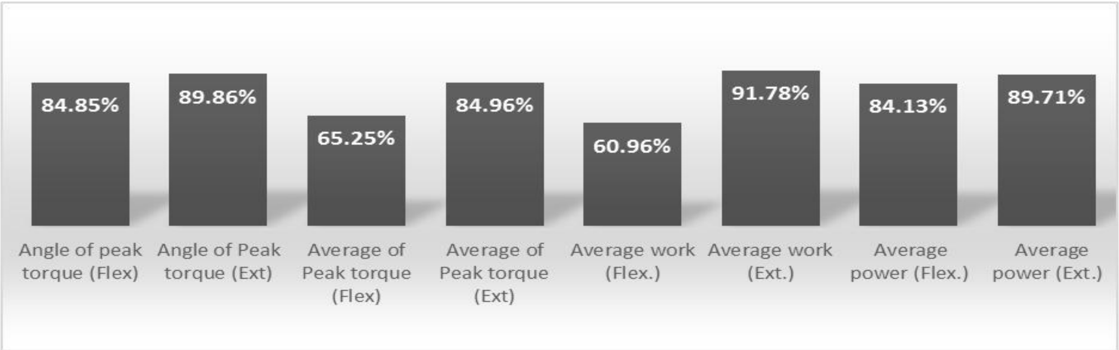
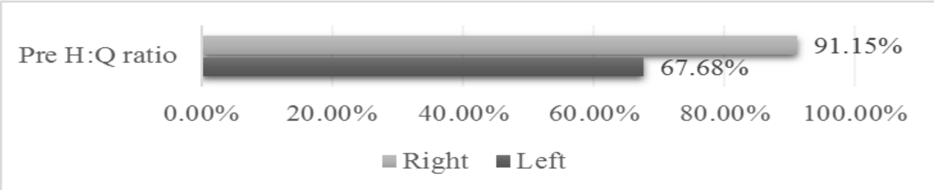


Figure 2 Left and right leg (H:Q) ratios before applying conditioning protocol.



Based on (table 4), left to right leg ratio of average peak torque during (Flex) was (65.25%) and during (Ext) was (84.96%) as displayed in (figure 1).The (H:Q) ratios calculated were (91.15%) for the dominant leg, and (67.68%) for the non-dominant leg (Figure 2). The existence of ipsilateral strength discrepancy between agonist (H) and antagonist (Q) muscles in the injured leg was indicated, in addition to the existence of strength deficits and bilateral strength asymmetry.

Table 5 Isokinetic variables differences between left and right leg muscles during (Flex) and (Ext) at the full range of movement (After conditioning).

Isokinetic variables (N=10)	Unit	Left		Right		T- test	MD
		M	± SD	M	± SD		
1. Angle of peak torque (Flex)	(º)	99.00	6.58	105.00	3.77	-3.23*	-6.00
2. Angle of peak torque (Ext)	(º)	136.00	4.21	141.00	2.86	-5.00*	-5.00
3. Peak torque (Flex)	(N·m)	98.00	6.32	123.00	2.78	-11.30*	-25.00
4. Peak torque (Ext)	(N·m)	112.00	5.43	133.00	5.47	-15.65*	-21.00
5. Work (Flex)	(J)	148.50	2.17	159.50	2.17	-11.38*	-11.00
6. Work (Ext)	(J)	189.20	1.61	201.50	1.84	-17.57*	-12.30
7. Power (Flex)	(w)	67.00	1.82	79.00	3.12	-10.39*	-12.00
8. Power (Ext)	(w)	70.00	4.21	77.00	4.13	-5.45*	-7.00
Total		**919.70**	**20.98**	**1019.00**	**15.38**	**-27.40**	**-99.30**

M, mean; SD, standard deviation; MD, mean difference;* significance level (P < 0.05)

(Table 5) displays isokinetic variables measured after applying conditioning protocol. Differences in average of peak torque, average work and average power between left and right (H) muscles were (-25.00, -11.00, -12.00) compared to (Q) muscles (-21.00, -12.30, -7.00) respectively, while difference in peak torque angle between left and right (H)) muscles was (-6.00) in comparison to (-5.00) for (Q) muscles.

There was a significant decrease in differences between left and right leg during (Flex) and (Ext), in addition to a noticeable increase almost in all isokinetic variables under testing. Specially, average of peak torque at (flex) and (Ext). Left and right leg average of peak torque during (Flex) measured was (98-123 N·m), and during (Ext) was (112-133 N·m respectively).

Figure 3 Left to right muscles ratios during (Flex) and (Ext) at the full range of movement (after conditioning).

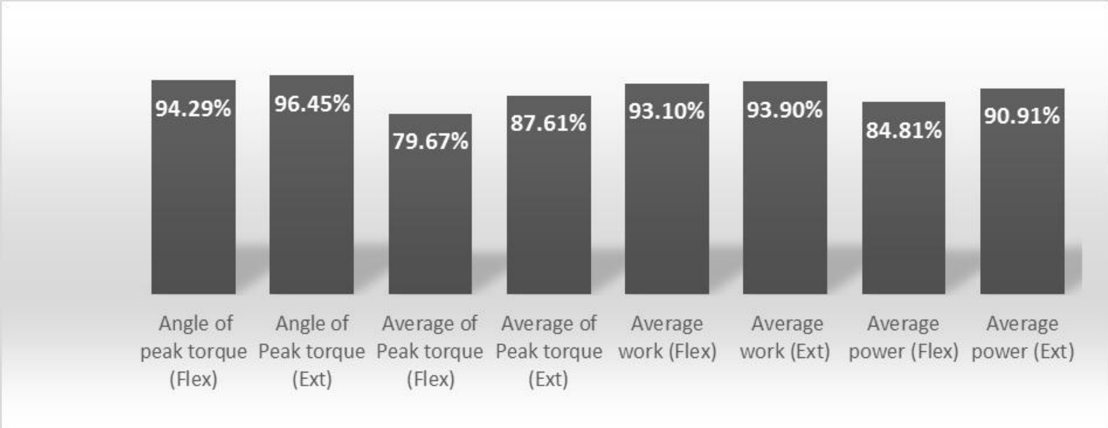
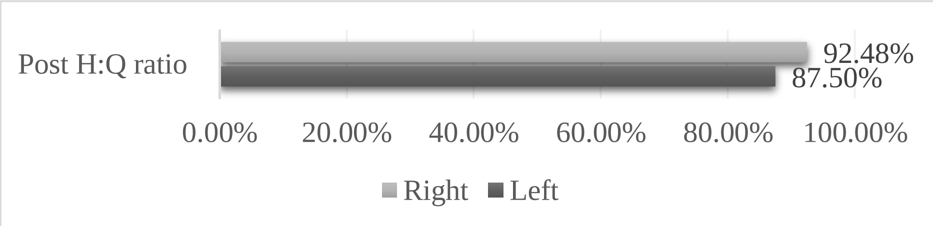


Figure 4 Left and right leg (H:Q) ratios after applying the conditioning protocol.



Based on (Table 5), The (H:Q) ratio calculated for the dominant leg was (92.48%), and the non-dominant leg was (87.50%) as displayed in (Figure 4), and left to right leg ratio of average peak torque during (Ext) was (87.61%), and during (Flex) was (79.67%) as displayed in (Figure 3). The study results reflected the positive effect of the proposed isokinetic conditioning protocol in decreasing ipsilateral strength discrepancy and adjusting bilateral hamstring strength asymmetry.

Table 6 Difference in subject's performance variables before and after proposed protocol.

Performance variables (SSET)		BR	AR	AC
Duration	Stage No.	0	7	9
	Run No.	0	3	2
Maximal speed (m.s^{-1})		0	2.13	2.45

BR, before rehabilitation; AR, after rehabilitation; AR, after conditioning

(Table 6) displays (SSET) results before and after the proposed protocol. It was noticeable that subject's maximal speed increased (0.32 m.s^{-1}) and completed two additional test stages.

Discussion

Muscles balance which is defined as the relationship between muscle group and another muscle group, is expressed in term of strength ratios between (agonists –antagonist) in the same joint (Nickols et al., 2007), may have a bearing on both performance technique and injury prevention. In children and adolescents who practice sport at either the recreational or competitive level (Hickey et al., 2009) have confirmed the correlation between presence of strength asymmetries of the two lower limbs and a high risk of injury. (Askling et al., 2003; Petersen et al., 2011) reported that hamstring specific eccentric strength training significantly reduced hamstring injury in Sweden soccer players.

It is logical to speculate that with long-term training effects, strength asymmetry may be present in some sports that involve unilateral movements. In our study, we suggested that it is essential to know the strengths and weaknesses of joints and muscle groups as a general trend, and for individual athletes when assigning frequency and volume of exercises. As well, the sequence of exercises usually depends on which areas need priority for individual athletes (Aquino and Leme, 2006; Balague et al., 2001).

Furthermore, (Croisier et al., 2008) have found that soccer players with uncorrected preseason hamstring strength imbalance had a significantly higher rate of hamstring strain injury in comparison to those without preseason hamstring strength imbalance, and to those with confirmed correction of preseason hamstring strength imbalance.

In another study (Newton et al., 2006) have discovered greater discrepancy in bilateral leg muscle strength in two groups of injured softball players and track and field athletes compared to uninjured. Similarly, in our study the initial isokinetic test results after applying rehabilitation protocol revealed the existence of strength deficits and bilateral strength asymmetry. Differences in average of peak torque, average work and average power between left and right (H) muscles were (-36.00, -40.80, -10.00) compared to (Q) muscles (-14.00, -9.00, -7.00) respectively. The (H:Q) ratios calculated were (91.15%) for the dominant leg and (67.68%) for the non-dominant leg, with (23.47%) discrepancy in bilateral leg muscle strength.

The (H:Q) ratios obtained were more than the (15%) discrepancy limit to prevent injuries previously suggested by (Wyatt and Edwards, 1981; Knapik et al., 1991; Kim et al., 2001; Aquino and Leme, 2006; Roy et al., 2012), and it could clarify subject's injury reoccurrence after rehabilitation without the appropriate conditioning programs. Relatively in Australian football, (34%) of the players reinjured their hamstring muscles within a year of returning to play after their initial hamstring strain injuries (Orchard and Seward, 2002). Also, they had the highest risk (13%) of recurrence of hamstring muscle strain injury during the first week of returning to play (Orchard and Best, 2002).

Although subject's performance was enhanced after rehabilitation protocol, results from the (SSET) revealed deficiency in maximal speed (2.13 $m.s^{-1}$) and endurance (stage 7, run 3). In our opinion, low average of peak torque and average work were the main reasons for performance limitation.

The significant reduction in lower limb asymmetry observed after applying the isokinetic conditioning protocol reflected the positive effect induced to restore the desired values of the concentric ratio and muscle strength. According to our findings, differences in average of peak torque, average work and average power between left and right (H) muscles were (-25.00, -11.00, -12.00) compared to (Q) muscles (-21.00, -12.30, -7.00) respectively. The (H:Q) ratios calculated for the dominant leg were (92.48%), and the non-dominant leg (87.50%), with (4.98%) discrepancy in bilateral leg muscle strength balance and (19.82%) amelioration in the non-dominant leg strength balance. As a result of the conditioning protocol and reduction in lower limb asymmetry, subject's performance increased (0.32 $m.s^{-1}$) and completed two additional test stages, to reach maximal speed of (2.45 $m.s^{-1}$) and (stage 9, run 2) of endurance.

We agree with (P. L. Bernard et al., 2012) that determination of the joint angle at the occurrence of maximum peak torque is directly dependent on several factors: the assembly of the joint, the muscular group tested, the type of practice (endurance versus maximum strength) and the level of practice.

Angle of peak torque has been shown to be significantly lower in previously damaged hamstrings than in uninjured hamstrings (Proske et al., 2004) which are, subsequently, at an increased risk of future injury (Brockett et al., 2004). (Orchard, 2001; Woods et al., 2004) found no significant difference in angle of peak torque in the incidence of a hamstring injury between the dominant and non-dominant leg. A study by (Clark et al., 2005) suggest the non-dominant limb may be at a higher risk of injury due to a lower angle of peak torque. Moreover, the same study found the angle of peak torque in the dominant limb to be significantly greater than in the non-dominant limb at the same velocity in male amateur football players.

In accordance with the findings of the present study and the change of peak torque angle measured after the conditioning protocol, we suggest that a change in the angle of peak torque is likely to be a result of injury; shorter optimum muscle length; tissue healing or other variables, but not due to limb dominance. Further investigation regarding the relations between angle of peak torque and other overlapping variables is needed.

In our opinion it is essential to assess the muscle balance in all sports skills, and all instantaneous positions to identify strength ratio for all (agonists – antagonist) skeletal muscles, in addition to ensure that training programs include balanced bilateral exercises for the major muscle groups at the full range of movement (Rabita et al., 2005). Based on the results of our study, we can confirm that isokinetic strength measurements of quadriceps and hamstrings in squash have a decisive importance for rehabilitation and training purposes. As well, it provides coaches with valuable information regarding the strength deficits of specific muscle group.

It appears that healthy athletes form different sports activity develop different muscular strength profiles. However, there is no consistent data regarding (H:Q) ratios being sport-specific, some previous studies reported no significant differences in (H:Q) ratio between different sports (Zakas et al., 1995; Rosene et al., 2001; Roy et al., 2012). The previous studies' controversial data requires further investigation to determine specific sport muscular strength profiles.

We suggest that isokinetic evaluations of knee muscles' strength in squash and their prompt interpretation are crucial for building an idea regarding squash athletes' physical conditioning. They may be beneficial in the follow-up of rehabilitation programs or when assessing training and performance. Our study Focus was on rehabilitating and conditioning for an injured male subject, thus a comparison between his isokinetic measurements and other healthy subjects could not be established. Therefore, a comparative study between healthy and injured squash athletes regarding muscular strength profiles is required.

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