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Pole Vault Practice and Rotator Cuff Strength: Comparison Between Novice and Competitive Athletes

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This study measured imbalances in rotator cuff strength in the dominant and non-dominant shoulders of novice and competitive pole vaulters. The aim was to determine whether muscular imbalances were related to the level of expertise of the pole vaulters. Fourteen young men (6 competitive athletes and 8 novices) participated in this study. The participants performed isokinetic tests of shoulder strength and simulated competition vaults. The isokinetic tests assessed the concentric (Con) and eccentric (Ecc) strength of the Internal (IR) and External Rotators (ER) of both shoulders. They were performed in the seated 90° abducted position in the scapular plane at 1.57 rad·s^{-1}, from 0° to 90°. The isokinetics results corresponded to peak torque. During vaults, the shoulder flexion/extension were videotaped in the sagittal plane. The experts' ER Con/IR Con ratio was significantly ($P<0.05$) higher in the dominant shoulder than in the non-dominant shoulder, whereas the novices showed no significant difference. The eccentric torque for the dominant IR was stronger than for the non-dominant IR for the experts but not the novices. At toe-off, the dominant shoulder flexion was significantly higher for the experts than the novices and correlated with the level of performance and with the eccentric strengths of the IR for the expert group. The pole vault practice trends to enhance ER strength in concentric and IR strength in eccentric in the dominant shoulder in order to improve the take-off phase of the vault.

Keywords: *Isokinetics, shoulders, muscular strength imbalance, pole vault.*

INTRODUCTION

The pole vault is an athletic discipline that requires high ability in sprinting, jumping, as well as high strength (Anderson, 1997; Linthorne, 2000). The shoulder muscles are highly solicited during pole vaulting, mainly at the time of take-off and during the rotation about the shoulders to pull up on the pole. At the take-off, just after the pole is planted in the take-off box, the dominant upper arm is extended directly above the head. The pole begins to bend due to the effect of the run-up kinetic energy of the pole vaulter. As the pole is planted, the athlete attempts to maintain the orientation of the arms and torso through muscular activation. However, the ground reaction force of the pole is too great. The arms are pushed behind the shoulders and the torso behind the hips. Consequently, a part of the kinetic energy is dissipated as heat in the vaulter's muscles and by inelastic stretching of the tendons and ligaments as the body is hyperextended (Linthorne, 2000) and more the pole is rigid, more the vaulter must be able to resist at the reaction force of the pole (Gros and Kunkel, 1990; Angulo-Kinzler *et al.*, 1994). Moreover, Arampatzis *et al.*(1999, 2004) determined that additional energy is linked to the muscular work during the rotation about the shoulders, at the Maximum Bending of the Pole (MPB). The study by Mc Ginnis and Bergman (1986) indicated that the histories of the resultant moments at the shoulder joint was of the same kind of the general moment exerted on the pole. These authors explained that this peak moments were relatively large compared to the peak shoulder joint for a variety of movements and suggested the importance of shoulder muscle strength in elite pole vaulter.

The shoulder joint is capable of developing very high strength in several sports, particularly asymmetric sports. Overhead activities require intense use of the shoulder joint to obtain the highest level of performance. However, the shallowness of the glenoid fossa and the disproportionate size and lack of congruency of the articular surfaces make the glenohumeral joint inherently instable (Culham and Peat, 1993). Stability is essentially dependent on capsule-ligamentous structures and the musculo-tendinous cuff. Thus, the shoulder muscles, and mainly the rotator cuff, must manage two complementary tasks: to produce maximal torque for performance and to maintain the integrity of the shoulder joint. The well known muscular coordination of the rotator cuff during the shoulder flexion/extension-abduction/adduction in overhead activities (Perry, 1983; Bradley and Tibone, 1991) permits to describe the muscular action of the rotator cuff during a pole vault. The movements are simultaneously generated by the concentric (Con) contraction of the agonist muscles and slowed down by eccentric (Ecc) contraction of the antagonist muscles (Scoville *et al.*, 1997). To perform a shoulder flexion-abduction, the humerus must describe an external rotation soliciting the agonist group the External Rotator (ER) muscles - while the antagonist group corresponds to the Internal Rotator (IR) muscles. Conversely, when the shoulder is in extension-adduction, a humeral internal rotation is associated, contracting the IR in concentric and the ER in eccentric. The vaulter plants his pole in the box with an abduction movement of the dominant shoulder (superior hand). The associated arm then realizes an extension movement to reach a final position stretched over the head. Consequently, the ER are in concentric mode (Figure 1*a*). At the time of contact, the arms and torso are deflected backwards: the ER are still in concentric mode, whereas the antagonist IR are in eccentric mode to limit the hyper-flexion of the shoulder joint (Figure 1*b*; Perry, 1983; Bradley and Tibone, 1991). During the bending phase, the rotation of the pole vaulter about the shoulders is combined with an extension of the shoulders. The IR are now in concentric mode and the ER in eccentric mode. (Figure 1*c*). This shoulder extension occurs in a closed kinetic chain, causing a lower ER Ecc strength than during the accompanying phase at the end of a ballistic movement, like a throw.

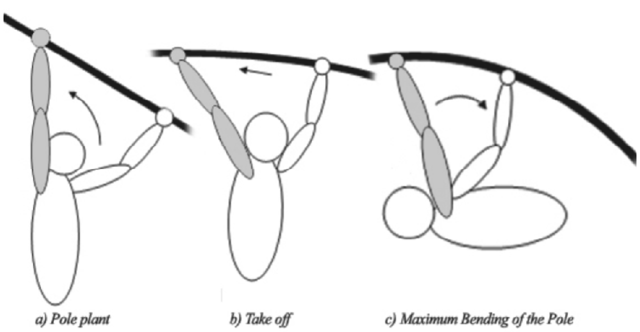

Figure 1: Movement of the dominant arm (in grey) between the pole plant and maximum bending of the pole. (a) The external rotation of the humerus, contracting the ER in Con; (b) the force exerted by the pole induces a high Ecc strength of the IR; (c) Until the maximun bending of the pole, the angle between the humerus and the trunk decreases and the IR muscles are in Con. The arrows represent the sense of the movement of the dominant arm.

By determining the IR/ER ratio, we can detected a muscular imbalance between the agonist and antagonist muscles. Given the structure of the shoulder joint, imbalances of the rotator cuff strength can generate instability of the glenohumeral joint. Thus, the study of muscular ratio permits to prevent shoulder joint injuries.

The aim of this study was to identify in pole vaulters differences in strength between IR and ER, between dominant and non-dominant shoulders, and between novice and competitive vaulters. A further goal was to identify differences in dominant shoulder flexion during a pole vault as a function of the level of expertise. These analyses will broaden our understanding of the consequences of pole vaulting on the musculoskeletal structures by determining the potential for injury.

METHODS

Participants

The main characteristics of the participants are presented in Table 1. All the participants were male volunteers (the protocol was fully explained to them and they all gave their informed consent before testing began) and all were currently practicing pole vault. The project was approved by the ethics committee of the University of Rouen. The novice pole vaulters were students at the Faculty of Sports Science, University of Rouen (France). They had all had introductory classes in pole vaulting as part of their studies at the faculty, but had never previously practiced this sport. The competitive pole vaulters practiced this activity daily at the National Institute of Sports (INSEP) in the elite group.

Table 1
General characteristics (means ± s) of the two groups of participants

		Age (year)	*Height (cm)*	*Mass (kg)*	*Personal record (m)*	*Level of expertise (% of World Record)*
Competitive group (n = 6)	Mean (± s)	23.5 (2.8)	181.2 (6.4)	77.3 (9.0)	4.75 (0.60)	77.4 (9.7)
Novice group (n = 8)	Mean (±s)	20.9 (1.0)	180.8 (7.6)	74.4 (5.5)	2.90 (0.37)	47.2 (6.1)

The novice vaulters used a mean pole of 4 m and the rigidity corresponded to a mass of 50 kg, whereas the competitive vaulters used a mean pole of 5 m and the rigidity corresponded to a mass of 90 kg. All participants were asymptomatic and free from musculoskeletal shoulder injuries at the time of testing. No participant in this study had had prior shoulder surgery nor had any shoulder abnormalities been diagnosed.

Isokinetic Procedure

The tests were performed on a Biodex® dynamometer (Biodex Medical Systems, Inc., NY). The participants were in the seated 90° abducted test position in the scapular plane (forward flexion of 30°) at 1.57 rad·s^{-1}, and the range of motion was 0° to 90° for both shoulders. The horizontal position of the arm corresponded to 0° (Figure 2). This position was selected to precisely measure the rotator cuff strength, whereas the use of this angular velocity has several interests: a low angular velocity is needed (a) to ensure the reproducibility of the measured maximal strength, because of the force-velocity relationship of the muscular concentric contraction (Alderink and Kuck, 1986; Hageman *et al.*, 1989; Ellenbecker, 1996; Shklar and Dvir, 1995), (b) to decrease the isoacceleration and isodeceleration phases during the range of motion (Westing *et al.*, 1991) and (c) to have a safe speed avoiding injuries linked to eccentric contractions (Scoville *et al.*, 1997; Sirota *et al.*, 1997; Ng and Lam, 2002).

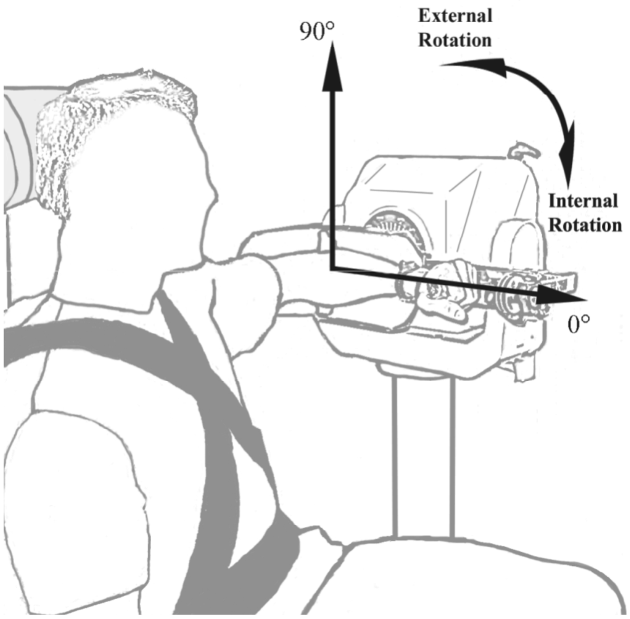

Figure 2: Body position on the isokinetic dynamometer.

The choice of the scapular plane has multiple justifications. It most closely reproduces the movement of pole vault (just before planting the pole, the athlete effectuates an elevation of the arm in the scapular plane) and it is better for assessing the rotator muscles for physiologic and anatomic reasons (Borsa *et al.*, 2003). Indeed, two observations suggest that the shoulder movements are centred in this plane: (a) the relaxation of the capsule is maximum (Gagey *et al.*, 1987), and (b) holding tight to an object, even if it is placed laterally, requires visual control, causing an automatic rotation of the trunk and the use of the upper limb in the scapular plane. According to Greenfield *et al.* (1990), the ER develop greater strength during assessment in the scapular plane compared with the frontal plane.

The isokinetic assessment was divided into two tests: (1) the assessment of the maximal strength of the ER in concentric and eccentric modes, at 1.57 $rad \cdot s^{-1}$, and (2) the assessment of maximal strength of the IR in eccentric and concentric modes, at 1.57 $rad \cdot s^{-1}$. There is a large difference regarding isokinetic shoulder testing procedures and rest time. On one hand, some studies randomized the tests and the first evaluated shoulder was still the same (Wilk *et al.*, 1993; Scoville *et al.*, 1997; Wang *et al.*, 2000; Wang and Cochrane, 2001; Ng and Lam, 2002). On the other hand, previous studies randomly ordered the evaluated extremity and the testing procedure had no randomization (Ellenbecker, 1996; Dupuis *et al.*, 2003, 2004; Noffal, 2003). Considering that the IR muscles are still stronger than the ER muscles in concentric as well as in eccentric mode (Shklar and Dvir, 1995) and that the aim of our study was to identify the difference between both sides, the order of the assessed side was randomly assigned to minimize the effect of learning bias (Ellenbecker, 1996), whereas the first test was always done before the second one. Moreover, each participant was given a 3-minute break between tests to ensure the regeneration of the anaerobic phenomenon (Shklar and Dvir, 1995; Voisin *et al.*, 1998), caused by the eccentric contractions and the low angular velocity used. For both tests, there were five internal rotations and five external rotations. An explanation of the testing procedure and standardized verbal instructions were given to each participant prior to beginning the test.

A global warm-up was performed beforehand. Both shoulders were warmed up using a rubber band for 10 minutes. This rubber band warm-up was composed of internal/external rotations and flexion/extension movements of the shoulder. Then, the isokinetic warm-up was performed on the isokinetic dynamometer in the position of the assessment in concentric mode for ER and IR, at a velocity of 2.09 $rad \cdot s^{-1}$. This higher angular velocity allows the participant to effect movements in submaximal contraction, in order to familiarize the participant with the range of motion and the accommodating resistance of the isokinetic dynamometer (Wilk *et al.*, 1993; Scoville *et al.*, 1997; Ng and Lam, 2002; Noffal, 2003). The participants performed 10 series, and contractions of IR and ER were considered one series. Verbal encouragement was given to the participants during all trials.

Pole Vault Session

All the participants performed three complete pole vaults. Each athlete had to perform three pole vaults at 90% of their respective personal best performances. The three vaults were separated by 4-minute rest periods, to control fatigue. This recovery time was assumed to be sufficient (Reilly *et al.*, 1990; Grant *et al.*, 2003) to perform all the pole vaults with a complete run-up at maximal intensity. The warm-up consisted of a jogging for 10 minutes, stretching and specific exercises for pole vaulting.

The vaults were videotaped from the last touch-down (TD) of the take-off foot to the MBP. All the vaults were made in a standardized jump area, as set by the International Association of Athletics Federation (IAAF). Two fixed digital video cameras (50 Hz, Panasonic®), with a shutter speed of 1/1000s, were placed in the sagittal plane corresponding to the dominant arm of the pole vaulter. Video camera 1 was placed at the take-off (parallel to the foot) and video camera 2 at the beginning of the take-off box. Both video cameras were placed 6 m from the line of the run-up zone. Video camera 1 had a height of 1.35 m and video camera 2 a height of 1.58 m (Figure 3). These heights permitted to record all participant limbs and reduced the effects of parallax. Marks placed on the ground were used to shift the first video camera according to the grip height of each athlete and to ensure the reproducibility of the measures. The articular measurement corresponded to the hyper-flexion of the dominant shoulder from the TD to the MBP. Marks were also placed on the body: (1) acromion,

(2) lateral epicondyle of the humerus, and (3) the superior edge of the iliac ridge. Joint measurements were made using Dart Trainer® software from Dart Fish™ (with an accuracy of 0,1° and a calibrating of s=0,5°) and were recorded in 2D from the last step to MBP.

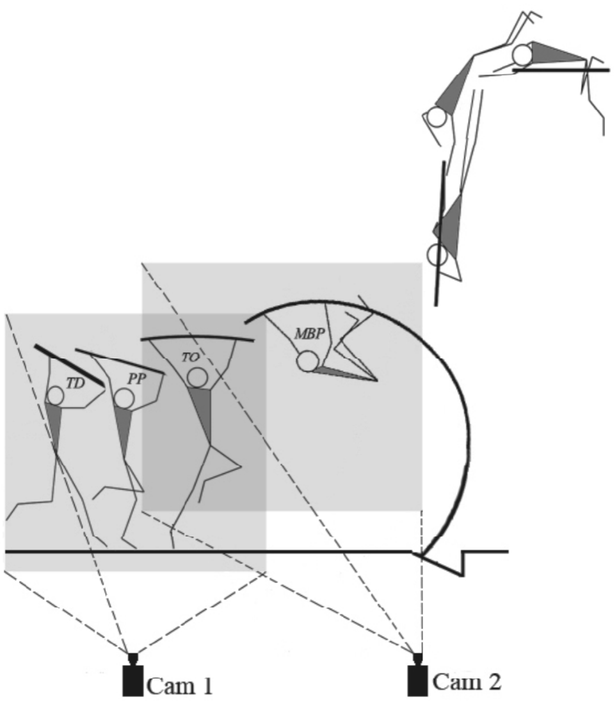

Figure 3: Position of the video cameras for recording the shoulder flexion between the last step and the MBP. TD = Touch-down; PP = Pole Plant; TO = Take-Off and MBP = Maximum Bending of the Pole.

Data Analysis

The values of the isokinetic assessment were recorded with software from the Biodex® dynamometer (Biodex Medical Systems Inc., NY). The results were expressed in Newton-meters to body weight (N·m·kg^{-1}BW) and they corresponded to peak torque (Hageman *et al.*, 1989; Wilk *et al.*, 1993). The shoulder flexion were recorded at six events of the vault: last touch-down, pole plant, take-off, beginning of the swing phase of the take-off leg, legs closed, and MBP. These six events are selected because they occur for all levels of expertise and are inevitable during the execution of a pole vault.

All the statistical tests are made using Statview® software (Abacus Concepts, Inc., Berkeley, CA, 1992). The normal distribution (Kolmogorov-Smirnov test) and the homogeneity of variance (Fisher F-test) are verified for each variable and allowed parametric statistics. Statistical significance was accepted at $P<0.05$. Student *t*-test are used to compare the two arms (paired groups) and the two groups (non-paired groups). A stepwise regression analysis and correlation were effectuated to link the angle of shoulder flexion with the muscular strength relative to the level of expertise.

RESULTS

ER Con/IR Con ratio

The ER Con/IR Con ratio was significantly higher for the dominant shoulder than the non-dominant shoulder in the competitive group. The ratio of the dominant shoulder was 0.639 (s = 0.104) and of the non-dominant shoulder it was 0.577 (s = 0.089). In the novice group, there was no significant difference between the ratios. The ER Con/IR Con ratio of the dominant shoulder was 0.643 (s = 0.179) and the ratio of the non-dominant shoulder was 0.541 (s = 0.226).

IR Eccentric Strength

The peak torque of IR in eccentric mode was significantly higher for the dominant shoulder than the non-dominant shoulder in the competitive group, whereas the novice group showed no significant difference. The competitive participants had a mean of 0.831 N·m·BW^{-1} (s=0.157) for the dominant shoulder and 0.761 N·m·kg^{-1}BW (s=0.179) for the non-dominant shoulder. The novice participants had a mean of 0.782 N·m·kg^{-1}BW (s=0.136) for the dominant shoulder and 0.744 N·m·kg^{-1}BW (s=0.118) for the non-dominant shoulder.

Angles of Dominant Shoulder Flexion

Table 2 shows the measurements for the competitive and novice participants. The shoulder flexion and hyper-flexion of the competitive participants were greater than in the novice participants. But the differences were only significant for three moments from the last step to the MBP. Significant differences were noted between the competitive and novice participants at the take-off, when the legs were closed and at MBP.

Table 2
Shoulder flexion (in degrees) of the dominant shoulder at 6 moments of the pole vault for novice and competitive groups

Pole vault events	*Competitive (mean±s)*	*Novice (mean±s)*	*Difference*
Last touch down	158.1 (8.9)	154.7 (9.2)	N.S.
Pole Plant	177.5 (13.4)	171.8 (8.7)	N.S.
Take-off	181.6 (9.6)	168.6 (10)	*
Beginning of the swing phase of the take-off leg	175.6 (5.7)	167.7 (17.2)	N.S.
Legs closed	158.1 (10.2)	135.9 (24.8)	*
MBP	111.6 (4.4)	158.1 (13.9)	*

* = significant difference at $P<0.05$; N.S. = non-significant

Finally, the results from the stepwise regression analysis show that significant predictor of the level of expertise - *i.e.* the performance in pole vaulting - is the angle of shoulder flexion at take-off ($r^2=0.40$, $p<0.05$; Figure 4). The relationship between the level of expertise and the angle of shoulder flexion at take-off is relatively strong (r=0.63).

Moreover, the angle of shoulder flexion at take-off is correlated with the eccentric strength of the IR of the dominant shoulder (r=0.70) only for the competitive group.

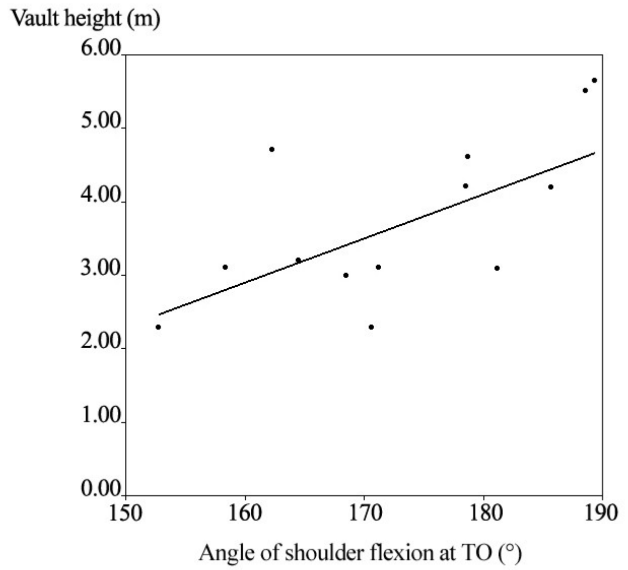

Figure 4: Strength of prediction of the performance (in meter) by angle of shoulder flexion (in degrees) at take-off (TO).

DISCUSSION

An assessment of the strength of the rotator cuff is of major importance in overhead sports (Alderink and Kuck, 1986; Dupuis *et al.*, 2003, 2004; Noffal, 2003). However, no scientific study has ever analysed the rotator cuff strength in pole vaulters. The specificity of this activity is that it is not a ballistic movement from take-off to MBP. Consequently, the forces are directly inflicted on the body and more particularly on the shoulders.

The results concerning the ER Con/IR Con ratio agreed with earlier works on the concentric strength of the rotator cuff. Indeed, several studies have shown a significant difference in the ER Con/IR Con ratio between the dominant and non-dominant shoulders (Wilk *et al.*, 1993; Wang *et al.*, 2000; Wang and Cochrane, 2001). The result indicates that the balance of the concentric strength of the rotator cuff is linked with the level of expertise. It would mean that an intensive practice in pole vaulting increases the difference between the dominant and the non-dominant shoulder. The ratio of the dominant shoulder was significantly higher than that of the non-dominant shoulder, indicating that the ER develop greater concentric strength in the dominant shoulder. Moreover, the IR did not present any difference in concentric strength between the two shoulders. Consequently, the practice of pole vault trends to improve ER strength in the dominant shoulder, particularly when the dominant arm is elevated just before the pole is planted in the box, when the dominant ER are solicited (Perry, 1983; Bradley and Tibone, 1991). During the intensive practice of the competitive pole vaulters, the high repetition of this movement would likely explains this increase in ER strength.

The results concerning IR eccentric strength agreed with those of earlier studies (Shklar and Dvir, 1995; Wang *et al.*, 2000; Wang and Cochrane, 2001). These works concluded that practising an overhead asymmetric sport creates a significant difference in IR eccentric strength between the dominant and non-dominant sides. Thus, pole vault is likely to increase IR strength in the eccentric mode on the dominant side. The difference in eccentric IR strength between the dominant and non-dominant sides was significant only for the competitive pole vaulters. The dominant shoulder is subjected to high forces, mainly between the plant of the pole (PP) and the take-off (TO) (Linthorne, 2000). And the study by Mc Ginnis and Bergman (1986) determined, during 0.18 s after TO, a movement of shoulder flexion before the extension. Consequently, between PP and a lapse of time after TO, the dominant IR are in eccentric mode, while the non-dominant arm does not reach this level of shoulder flexion. Moreover, the pole applies an additional force (the ground reaction force of the pole) on the IR, increasing the difference in solicitation of the IR in eccentric mode of the two shoulders. This difference was not significant for the novice athletes, because the poles were softer and shorter than the poles used by the competitive participants. The longer and more rigid poles of the competitive athletes inflicted a higher ground reaction force on the dominant IR muscles of the hanging pole vaulter. The results confirmed that the pole vault is an asymmetric activity, and his intensive practice influences the musculoskeletal system of the dominant shoulder, particularly the rotator cuff.

The mean shoulder hyper-flexion of the competitive participants at toe-off was 181.6° (s=9.6). This value indicates that several competitive pole vaulters had a shoulder hyper-flexion higher than the theoretical maximum (=180°) and higher than the normal range of shoulder flexion (=168°) for male participants (Freedman and Munro, 1966; Boone and Azen, 1979). The novice participants, on the other hand, were in the normal range of shoulder flexion (168.6, s=10°). This difference in shoulder flexion shows the influence of using a longer and more rigid pole. Moreover, the morphologic characteristics of the two groups did not significantly differ, particularly regarding mass and height, whereas the level of expertise was significantly different between groups (Table 1). This indicates that the novice pole vaulters had a relatively low grip height and a pole whose rigidity was markedly lower than their mass. The inverse was true for the competitive vaulters. The study of Linthorne (2000) emphasized that the athlete is pushed backwards (arms and torso) during the planting phase. This creates a very high force that is dissipated in the body of the athlete. This phenomenon is correlated with the rigidity of the pole and with the strength of the arms-shoulders of the pole vaulter. Previous studies have demonstrated the high demand for muscular work, especially by the shoulders, to transmit additional energy to the pole (Arampatzis *et al.*, 1999, 2004). To conclude, this significant difference in shoulder hyperflexion reveals that the poles used by the competitive vaulters generated greater forces on these athletes than did the poles of the novice vaulters, causing an imbalance in the eccentric strength of IR. This result suggests that the increase in eccentric strength is correlated with joint elasticity. Indeed, the stepwise regression analysis indicated a significant link between the level of expertise and the angle of flexion, whereas this angle of flexion is correlated with the eccentric strength IR of the dominant shoulder only for the competitive vaulters. This link between the eccentric strength of the dominant IR and the angle of flexion trends to suppose that more the dominant shoulder is elevated, more the vaulter can produce bending strength on the pole and more the performance will be high.

This study points up the close relationship between sport practice, muscular strength and level of expertise. The capacities of the dominant shoulder are crucial for the execution of a pole vault. This shoulder explosively raises the pole and resists the forces created by it. These capacities increase with the level of expertise, as do velocity, grip height and the rigidity of the pole. The ER and IR of the non-dominant shoulder are less solicited because the shoulder flexion is minor. This different role explains the asymmetries in strength between the IR and ER muscles of both shoulders.

It would be interesting to perform a prospective study with elite pole vaulters using similar conditions of pole vaulting (pole rigidity and grip height) in order to follow the development or progression of the muscular imbalance. The number of pole vaults should also be increased to strengthen the power of the results. However, this study underlines the biological adaptations of the shoulder's muscular structures to an accumulation of mechanical loads, using a dynamometer and video recordings.

CONCLUSION

The main objective of this study was to assess the strength of the IR and ER of the dominant and non-dominant sides of pole vaulters to determine whether a muscular imbalance develops due to the intensive practice of this sport. The identified asymmetries provide greater understanding of the particular influence of the pole vault practice on the musculoskeletal system of athletes. Indeed, the results underline the different roles of the dominant and non-dominant shoulders. This difference acts on IR strength, particularly on the dominant side. To conclude, this research has established new knowledge, mainly regarding the strength of the rotator cuff. There are specific adaptations due to the practice of pole vault, and the results are similar to those for other sports characterised by shoulder flexion.

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