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# Effects of uni-podal muscle strengthening on muscle imbalances of hamstrings and quadriceps of sprinter -17 years

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**Abstract**

This study aims to identify the effect of a training program on sprint athletes proposed for a duration of 06 weeks using uni-podal strengthening exercises of the hamstrings in a preventive but. The sample consisted of an experimental group and a control group, each composed of 10 sprinters under the age of 17 training in the Sétifien Olympic Club for the 2021-2022 sports season. The results showed statistically significant differences in favor of the experimental regarding the uni-podal and mixed muscle race tests.

**Keywords: Keywords: maximal quadriceps strength, maximal hamstring strength, uni-podal muscle racio, mixed muscle racio.**

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## 1. Introduction

The assessment of the physical profile of athletes is of major interest for the estimation and prediction of performance in many sports (Chachou, 2022). Rapid changes in speed require a high rate of force development and some authors have recommended focusing training on the eccentric downward deceleration phase rather than the concentric phase of explosive movement (Turnbull JR, 2009). This is because the eccentric strength of the knee extensors and flexors with a higher concentric strength in elite athletes compared to lower level athletes. It should be taken into account that increased muscle stiffness and a very high extension and contraction speed can lead to significant injuries (Lyon., 2019). Such differences in muscle properties could be reflected by the force moment measured in isokinetic. Therefore, it is important to know the characteristics of each discipline to improve the quality of physical training (Gross M, 2010).

### 1- Theoretical framework

### 1-1-Sprint, mechanism of injury

The majority of hamstring injuries occur during running, but these injuries can also occur during slow, prolonged stretching or rapid stretching (Heiderscheit BC, 2010).

Biomechanical studies have reported that the hamstrings are activated during the entire stride cycle, but particularly during the end of knee extension when the lower limb is off the ground (free leg phase - overhead) and at the time of ground bearing. During the latter, the hamstrings reach their peak of elongation and have a braking role on the extension of the leg on the thigh by an eccentric contraction, which is a source of significant stress on the muscle (Guex K, 2013). Furthermore, compared to strength training exercises, the hamstrings show the highest electrical activity during sprinting (van den Tillaar R, 2017). In addition to these biomechanical aspects of the stride, it has been reported that hamstring muscle activity during the terminal phase of the free leg movement and their eccentric strength were associated with sprint performance (Morin JB, 2015).Thus, optimal hamstring muscle function is necessary for sprint performance, both for stride quality and performance.

### 1-2-Relevance of the hamstrings for motor skills

- The eccentric contraction is more physiological and therefore more functional, in fact it is used, among other things, to fight against gravity and inertia.

- The forces developed in eccentric contraction are, at equal speed, greater than in concentric contraction.

- Eccentric contraction is better tolerated by patients because it requires less energy and oxygen consumption.

- Eccentric contraction is more appropriate for spastic patients because during the contraction, the stretch reflex is triggered on the agonist and therefore participates in the movement. Although it can now be argued that isokinetic muscle strengthening does not worsen spasticity (Gain H, 2003).

## 1-3-Epidemiology

Hamstring injuries are among the most common lower limb injuries in athletes, accounting for up to 29% of all injuries in various sports. This injury is most common in sports requiring rapid acceleration such as running, hurdling, jumping and kicking (Erickson LN, 2017). In athletics, a meta-analysis of the proportions of injuries between different populations of runners, highlights that sprinters have the most injuries to the lower limbs, with 34.7% of injuries (Kluitenberg B, 2015). A 3-year study in athletics at the Penn Relays Carnival showed that hamstring injuries were the most common injury, accounting for 24.1% of all injuries and over 75% of all lower limb injuries Thus, hamstring injuries account for 50% of muscle injuries in sprinters. This injury is therefore a real problem in athletics (Opar DA, 2014).

## 1-4-Analysis of muscle coordination

Muscle coordination is defined as a distribution of muscle activation to produce a given combination of joint moments. The phenomenon of muscle coactivation is defined as simultaneous activation of muscles acting at the same joint (Osterning LR, 1999).

The role of the hamstring muscle group is recognized as important in the prevention of knee injuries (Hewett, 2005) (Hewett et al., 2005). Its co-activation allows dynamic stabilization of the knee and reduces the shear forces that can act on the ACL. This muscle group is composed of 3 chiefs: semimembranosus, semitendinosus and biceps femoris. When the knee is flexed, the semimembranosus and semitendinosus are internal rotators of the knee, while the biceps femoris is an external rotator. These different functions imply a different treatment in the prevention of ACL injuries. The semitendinosus appears to be particularly important as its contraction has the potential to compress the medial part of the knee joint and thus limit excessive external rotation and consequently reduce ACL injury. Low activation of the semitendinosus combined with high activation of the vastus lateralis of the quadriceps has been shown to increase the risk of ACL injury (Zebis, 2009).

The choice of strength training exercises therefore appears to be of primary importance. First of all, it is important not to neglect the hamstrings which play an agonistic role. It is also important to strengthen the knee extensor muscles, the quadriceps. However, too much activation of the quadriceps compared to the hamstrings leads to increased shear forces on the ACL. The study of hamstring/quadriceps coactivation (activation ratio between the hamstring and quadriceps muscle groups) during different exercises is therefore essential to optimize the prevention of ACL injuries (Croisier J. C., 1999).

The force ratio between the hamstrings and the quadriceps allows the balance between the agonist and antagonist muscles of the knee to be studied. These two muscle groups surrounding the knee joint play a crucial role. The antagonistic eccentric co-activation of the hamstrings opposes the concentric contraction of the quadriceps and vice versa.

## 1-5-Scientific approach to developing effective preventive measures

The objective is to provide athletes and their entourage with programs, strategies and/or methods that will reduce the occurrence of injuries (in number and/or severity). In a scientific and quality approach, it is important that the effectiveness of these measures has been evaluated. The diagnosis and rigorous recording of injuries are the fundamental basis for their prevention (Edouard P, 2018).

Quadriceps and hamstring muscle strength has been extensively studied for over 20 years now, thanks to the advent of isokinetic measurement devices. This work has focused on three main areas: the study of different populations in order to have a better approach to norms according to sex, age and physical and sporting activities (Zakas A, 1995). Then, the search for anomalies in relation to certain pathologies (rupture of cruciate ligaments of the knee, patellar syndrome, leg fracture, muscular accident, etc.) (Sabourin F, 1991). And finally, the search for prevention protocols.

The practice of high-level sprinting requires, among other things, important power qualities in the lower limbs. Thus, three elements appear particularly interesting in this monitoring of muscular strength: ensuring the absence of asymmetry between the dominant and non-dominant sides; ensuring the correct balance between the hamstrings and the quadriceps.

In concentric exercises, muscle strength decreases as the speed of the exercise increases. For a given speed, the force developed by the Quadriceps is greater than that of the Hamstrings (Watanabe T, 1993).

Understanding the involvement of the different factors determining the ability to accelerate the lower limbs in the performance of explosive movements could help refine training strategies, allowing them to improve training techniques, better individualize work sessions, target athlete assessments in relation to the physical qualities required or detect future champions on the basis of their physical potential and better understand physiological and morphological characteristics (Ugrinowitsch, 2007).

According to (Wrigley, 1998), unlike the upper limbs, there is no marked difference in strength in the lower limbs of athletes. Even if they practice an asymmetrical sporting activity (jumping, handball or football), the difference in strength between the dominant and non-dominant limb does not exceed 10%, in the absence of pathology of the locomotor system. It has also been shown that a muscle imbalance between the left and right lower limbs could potentially make the subject susceptible to injury. A threshold asymmetry of 10-15% or more is considered to place additional stress on the weak leg, compromising the athlete's performance and predisposing the athlete to various injuries (Hewit, 2012).

Therefore, it seems appropriate to incorporate compensatory hamstring strengthening into the athlete's usual training (Lammari f, 2015).

**1-6-Unipodal muscle training protocol to correct muscle imbalances**

Several studies have shown that exercises performed in the open kinetic chain of the lower limb increase the stresses on the ACL.

The advantages of unipodal training are multiple:

- it is a movement that is much more specific to the functions of daily life and to a large majority of sports. Indeed, walking and running involve alternating unipodal supports. - It is the movement that is used in all rehabilitation protocols. After an injury, the injured limb is frequently weaker than the healthy limb. When this happens, the use of a unipodal protocol is necessary to restore this balance.

- The unipodal position naturally creates an imbalance situation which, in unipodal strength training exercises, leads to the recruitment of the body's stabilizing muscles (which are not recruited in bipodal exercises). As a result, unipodal exercise would result in the recruitment of a greater number of muscle groups (intermuscular coordination) and therefore greater force production.

- Unipodal exercise allows proprioceptive work due to the instability created (Aouiche, 2013).

**1-7-Choosing the mixed ratio**

The use of the mixed ratio is based on several isokinetic studies which judged that this ratio was closer to the functional reality (Aagaard, 1998); (Croisier J. C., 1996). Indeed, the discriminating character of eccentric isokinetic evaluation has been explored by many authors (Croisier J. F., 2002). The authors observed, in a cohort of 462 professional football players evaluated at the beginning of the season, that 30% of the players identified as "unbalanced" were characterized by an exclusively eccentric anomaly. These players with a strength imbalance identified by isokinetics at the beginning of the season and not specifically treated, were characterised during the following season by a hamstring injury risk multiplied by 4 to 5 compared to players who were not muscularly "unbalanced" (Croisier J. G., 2008) (Solomonow, 2001).

Researchers have consistently proposed that the balance of these opposing muscles is imperative in maintaining the joint. This balance is therefore a critical factor in avoiding injury during dynamic athletic movements such as jumping, pivoting, etc. (Solomonow et al, 2001).

**1-8-Experimental protocol**

In order to respect muscle co-activation defined as simultaneous activation of muscles acting at the same joint (Osterning LR, 1999)during sprinting effort thus ensuring balance between agonist and antagonist muscles of the knee (Aagaard, 1998); (Croisier J. C., 1996) we chose two exercises: the quadriceps leg extensor and the hamstring sit-up leg curl performed unilaterally.

We first calculated the maximum quadriceps strength and the maximum hamstring strength of each lower limb of each athlete before the start of the training programme and then calculated the ratio of hamstring to quadriceps strength of each lower limb and the mixed ratio of the two lower limbs for each athlete. We then proceeded to design a training programme to establish the balance between the antagonistic knee muscles of each lower limb and between the two lower limbs of each athlete.

## 2-Analysis of the results

### 2-1-Comparison of population characteristics

#### 2-1-1-According to the results of age, weight and height

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| | age | | | | | |
| **control** | 15.05 | 0.59 | 0.59 | 2.82 | 0.05 | N/S |
| **experimental** | 15.00 | 0.41 | 0.47 | | | |
| **weight** | | | | | | |
| **control** | 67.36 | 5.35 | 3.63 | 0.15 | 0.05 | N/S |
| **experimental** | 66.87 | 3.85 | 4.56 | | | |
| **height** | | | | | | |
| **control** | 168 | 3.63 | 5.35 | 0.37 | 0.05 | N/S |
| **experimental** | 167 | 4.56 | 3.85 | | | |

Table 01: Results (age, weight and height) of the control and experimental sample

The age comparison of the two populations showed no significant differences between the control and experimental subjects (sig = 2.82 > α = 0.05). Thus, the two populations did not differ significantly in age.

The comparison of the weights of the two populations did not show significant differences between the control and the experimental sample (sig = 0.15 > α = 0.05). Therefore, the two populations did not differ significantly in weight.

The comparison of the height of the two populations did not show significant differences between the control and the experimental sample (sig = 0.37 > α = 0.05). Therefore, the two populations do not differ significantly in height.

#### 2-1-2-According to the results of the pre-test right quadriceps peak strength

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| | **FmaxQR** | | | | | |
| **control** | 27.3% | 2.58 | 0.34 | 0.79 | 0.05 | N/S |
| **experimental** | 26.9% | 2.6 | | | | |

Table 02: Right quadriceps peak strength results (pre-test of control and experimental sample)

The comparison of the maximum right quadriceps strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.79 > α = 0.05). Therefore, the two populations did not show significant differences in the maximum strength of the right quadriceps.

**2-1-3-Based on the results of the pre-test left quadriceps maximum strength**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| FmaxQL | | | | | | |
| control | 24.4% | 2.22 | 0,1 | 0.65 | 0.05 | N/S |
| experimental | 24.3% | 2.05 | | | | |

Table 03: Left quadriceps peak strength results (pre-test of control and experimental sample)

The comparison of the maximum left quadriceps strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.65 > α = 0.05). Therefore, the two populations did not show significant differences in the maximum strength of the left quadriceps.

**2-1-4-According to the results of the maximum right hamstring strength of the pre-test**

| | x | T | S | sig | α | |
|---|---|---|---|---|---|---|
| FmaxHR | | | | | | |
| control | 23.3% | 0.1 | 2.16 | 0.87 | 0.05 | N/S |
| experimental | 23.4% | | 2.31 | | | |

Table 04: Right hamstring peak strength results (pre-test of control and experimental samples)

The comparison of the maximum right hamstring strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.87 > α = 0.05). Therefore, the two populations do not show significant differences in the left hamstring.

**2-1-5-Based on the results of the pre-test maximum left hamstring strength**

| | x | T | S | sig | α | | |
|---|---|---|---|---|---|---|---|
| | FmaxHL | | | | | | |
| control | 21.5% | 0.88 | 1.26 | 0.76 | 0.05 | | N/S |
| experimental | 22.1% | | 1.72 | | | | |

Table 05: Left hamstring peak strength results (pre-test of control and experimental sample)

The comparison of the maximum left hamstring strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.76 > α = 0.05). Therefore, the two populations did not show significant differences in the left hamstring.

**2-1-6-Depending on the results of the right uni-podal muscle racio**

| | x | T | S | sig | α | |
|---|---|---|---|---|---|---|
| | | | **RaR** | | | |
| **control** | 15.62% | 0.52 | 6.5 | 0.41 | 0.05 | N/S |
| **experimental** | 14.19% | | 5.57 | | | |

Table 06: Results of the right uni-podal muscle racio (pre-test of control and experimental sample)

The comparison of the right unipodal muscular racio of the two populations showed no significant differences between the control and experimental subjects (sig = 0.41 > α = 0.05). Therefore, the two populations did not show significant differences in right unipodal muscle racio.

**2-1-7-Depending on the results of the left uni-podal muscle racio**

| | x | T | S | sig | α | | |
|---|---|---|---|---|---|---|---|
| | | | **RaL** | | | | |
| **control** | 12.77% | 1.41 | 7.19 | 0.05 | 0.05 | | N/S |
| **experimental** | 9.4% | | 2.17 | | | | |

Table 07: Results of the uni-podal muscle racio left (pre-test of the control sample and the experimental sample)

The comparison of the left unipodal muscular racio of the two populations showed no significant differences between the control and experimental subjects (sig = 0.05 = α = 0.05). Therefore, the two populations did not show significant differences in the left unipodal muscle racio.

**2-1-8-According to the results of the mixed muscle racio of the quadriceps**

| | x | T | S | sig | α | |
|---|---|---|---|---|---|---|
| | | | **MixedRa Q** | | | |
| **control** | 10.26% | 0.49 | 3.02 | 0.65 | 0.05 | N/S |
| **experimental** | 9.57% | | 3.17 | | | |

Table 08: Results of the right mixed muscle racio (pre-test of control and experimental sample)

The comparison of the mixed racio of the quadriceps muscles of the two populations did not show significant differences between the subjects of the control sample and the subjects of the experimental sample (sig = 0.65 > α = 0.05). Therefore, the two populations did not show significant differences in mixed quadriceps muscle racio.

**2-1-9-Based on the results of the mixed hamstring racio**

| | x | T | S | sig | α | |
|---|---|---|---|---|---|---|
| **MixedRa l** | | | | | | |
| **control** | 7.23% | 0.67 | 4.17 | 0.67 | 0.05 | N/S |
| **experimental** | 5.29% | | 3.22 | | | |

Table 09: Results of the left mixed muscle racio (pre-test of control and experimental sample)

The comparison of the mixed hamstring racio of the two populations showed no significant differences between the control and experimental subjects (sig = 0.67 > α = 0.05). Therefore, the two populations did not show significant differences in mixed hamstring racio.

**2-2-Comparison of post-test results between control and experimental samples**

**2-2-1-According to the results of the maximum force of the right quadriceps**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| | **FmaxQR** | | | | | |
| **control** | 30.6% | 1.64 | 1 | 0.32 | 0.05 | N/S |
| **experimental** | 29.9% | 1.44 | | | | |

Table 10: Right quadriceps peak strength results (post-test of control and experimental samples)

The comparison of the maximum right quadriceps strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.32 > α = 0.05). Therefore, the two populations do not show significant differences in the maximum strength of the right quadriceps.

**2-2-2-Based on the results of the maximum strength of the left quadriceps**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **FmaxQL** | | | | | | |
| **control** | 28.3% | 1.41 | 0.66 | 0.51 | 0.05 | N/S |
| **experimental** | 27.8% | 1.93 | | | | |

Table 12: Right hamstring peak strength results (post-test of control and experimental samples)

The comparison of the maximum right hamstring strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.06 > α = 0.05). Therefore, the two populations do not show significant differences in the left hamstrings.

**2-2-4-According to the results of the maximum strength of the left hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| FmaxHR | | | | | | |
| control | 25.4% | 1.77 | 0.75 | 0.45 | 0.05 | N/S |
| experimental | 26% | 1.66 | | | | |

Table 13: Left hamstring peak strength results (post-test of control and experimental samples)

The comparison of the maximum left hamstring strength of the two populations showed no significant differences between the control and experimental subjects (sig = 0.45 > α = 0.05). Therefore, the two populations do not show significant differences in the left hamstrings.

**2-2-5-Based on the results of the right uni-podal muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| RaR | | | | | | |
| control | 18.24% | 6.86 | 3.57 | 0.00 | 0.05 | N/S |
| experimental | 8.07% | 5.81 | | | | |

Table 14: Results of the right uni-podal muscle racio (post-test of the control and experimental samples)

The comparison of the right unipodal muscle racio of the two populations showed significant differences between the control and experimental sample subjects (sig = 0.00 > α = 0.05). Thus, the two populations showed significant differences in right unipodal muscle racio in favour of the experimental sample subjects for a calculated unipodal racio of 8.07% versus a calculated racio of 18.24% for the control sample subjects.

**2-2-6-Depending on the results of the left uni-podal muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| RaL | | | | | | |
| control | 13.26% | 8.11 | 2.48 | 0.02 | 0.05 | N/S |
| experimental | 6.41% | 3.16 | | | | |

Table 14: Results of the left uni-podal muscle racio (post-test of the control and experimental samples)

The comparison of the left unipodal muscle racio of the two populations showed significant differences between the control and experimental sample subjects (sig = 0.02 = α = 0.05). Thus, the two populations show significant differences in the left unipodal muscle racio in favour of the experimental sample subjects for a calculated unipodal racio of 6.41% versus a calculated racio of 13.26% for the control sample subjects.

**2-2-7-Based on the results of the mixed muscle racio of the quadriceps**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| MixedRa Q | | | | | | |
| control | 7.65% | 2.04 | 0.47 | 0.63 | 0.05 | N/S |
| experimental | 7.1% | 3.01 | | | | |

Table 15: Results of the right mixed muscle racio (post-test of the control and experimental samples)

The comparison of the mixed racio of the quadriceps muscles of the two populations did not show significant differences between the subjects of the control and experimental samples (sig = 0.63 > α = 0.05). Therefore, the two populations do not show significant differences in the mixed muscle racio of the quadriceps. Indeed, the development of the maximum strength of the right and left quadriceps was of little importance, while the development of the maximum strength of the right and left hamstrings was.

**2-2-8-Selon les résultats du racio musculaire mixte des ischio-jambiers**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| MixedRa H | | | | | | |
| control | 11.44% | 4.79 | 2.1 | 0.04 | 0.05 | N/S |
| experimental | 7.63% | 5.11 | | | | |

Table 16: Results of the left mixed muscle racio (post-test of the control and experimental samples)

The comparison of the mixed hamstring racio of the two populations showed significant differences between the control and experimental subjects (sig = 0.04 > α = 0.05). Thus, the two populations show significant differences in mixed hamstring muscle racio in favour of the experimental sample subjects for a calculated mixed racio of 7.63% versus a calculated racio of 11.44% for the control sample subjects.

**2-3-Comparison of the results between the pre-test and post-test of the control sample**

**2-3-1-Based on the results of the maximum strength of the right quadriceps**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| | FmaxQD | | | | | |
| control | 27,3% | 2.58 | 7.8 | 0.01 | 0.05 | S |
| experimental | 30.6% | 1.65 | | | | |

Table 17: Right quadriceps peak strength results (control post-test)

The comparison of the maximum right quadriceps strength of the control sample showed significant differences between the pre-test and post-test (sig = 0.01 < α = 0.05).

**2-3-2-Based on the results of the maximum quadriceps strength**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| FmaxQR | | | | | | |
| control | 24.4% | 2.22 | 11.2 | 0.00 | 0.05 | S |
| experimental | 28.3% | 1.41 | | | | |

Table 18: Maximum left quadriceps force results (post-test of the control sample)

Comparison of the maximum strength of the left quadriceps showed significant differences between pre-test and post-test (sig = 0.51 > α = 0.05).

**2-3-3-According to the results of the maximum strength of the right hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| FmaxHR | | | | | | |
| **control** | 23.3% | 2.16 | 2.92 | 0.02 | 0.05 | S |
| **experimental** | 25.3% | 3.09 | | | | |

Table 19: Maximum Right Hamstring Force Results (Post-Control Sample)

Comparison of the maximum strength of the right hamstrings showed significant differences between the pre-test and post-test (sig = 0.02 < α = 0.05).

**2-3-4-According to the results of the maximum strength of the left hamstrings of the pre-test**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| FmaxHL | | | | | | |
| **control** | 21.5% | 1.26 | 9.58 | 0.02 | 0.05 | S |
| **experimental** | 25.4% | 1.77 | | | | |

Table 19: Maximum Left Hamstring Force Results (Post-Control Sample)

Comparison of the maximum strength of the right hamstrings showed significant differences between the pre-test and post-test (sig = 0.02 < α = 0.05).

**2-3-5-According to the results of the right unipodal muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| RaR | | | | | | |
| **control** | 15.62% | 6.5 | 0.93 | 0.71 | 0.05 | N/S |
| **experimental** | 18.24% | 6.86 | | | | |

Table 20: Right unipodal muscle racio results (post-test of control sample)

Comparison of the maximum strength of the right unipodal muscle racio showed no significant differences between pre- and post-test (sig = 0.71 > α = 0.05).

**2-3-6-According to the results of the left unipodal muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **RaL** | | | | | | |
| **control** | 12.77% | 7.19 | 0.11 | 0.18 | 0.05 | N/S |
| **experimental** | 13.26% | 8.11 | | | | |

Table 21: Left unipodal muscle racio results (post-test of control sample)

Comparison of the maximum strength of the left unipodal muscle racio showed no significant differences between pre- and post-test (sig = 0.18 > α = 0.05).

**2-3-7-According to the results of the mixed quadriceps muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **MixedRa Q** | | | | | | |
| **control** | 10.26% | 3.02 | 2.64 | 0.4 | 0.05 | N/S |
| **experimental** | 7.65% | 2.04 | | | | |

Table 22: Right mixed muscle racio results (post-test of the control sample)

Comparison of the maximum strength of the quadriceps mixed muscle racio showed no significant differences between pre- and post-test (sig = 0.4 > α = 0.05).

**2-3-8-According to the results of the mixed muscle racio of the hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **MixedRa H** | | | | | | |
| **control** | 7.23% | 4.17 | 2.08 | 0.99 | 0.05 | N/S |
| **experimental** | 11.44% | 7.79 | | | | |

Table 23: Left mixed muscle racio results (post-test of control sample)

Comparison of the maximum strength of the mixed muscle racio of the hamstrings showed no significant differences between pre- and post-test (sig = 0.99 > α = 0.05).

**2-4-Comparison of results between pre-test and post-test of the experimental sample**

**2-4-1-According to the results of the maximum force of the right quadriceps**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| | | **FmaxQD** | | | | |
| **control** | 26% | 2.6 | 6.36 | 0.01 | 0.05 | S |
| **experimental** | 29% | 1.44 | | | | |

Table 24: Maximum right quadriceps force results (post-test of experimental sample)

Comparison of the maximum right quadriceps strength of the control sample showed significant differences between the pre-test and post-test (sig = 0.01 < α = 0.05).

**2-4-2-According to the results of the maximum quadriceps force**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **FmaxQG** | | | | | | |
| **control** | 24.3% | 2.05 | 21 | 0.00 | 0.05 | S |
| **experimental** | 27.8% | 1.93 | | | | |

Table 24: Left quadriceps maximum force results (post-test of experimental sample)

Comparison of the maximum strength of the left quadriceps showed significant differences between pre-test and post-test (sig = 0.00 < α = 0.05).

**2-4-3-According to the results of the maximum strength of the right hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **FmaxID** | | | | | | |
| **control** | 23.4% | 2.31 | 12.86 | 0.00 | 0.05 | S |
| **experimental** | 27.6% | 2.06 | | | | |

Table 25: Right hamstring maximum force results (post-test of experimental sample)

Comparison of the maximum strength of the right hamstrings showed significant differences between pre-test and post-test (sig = 0.00 < α = 0.05).

**2-4-4-According to the results of the maximum strength of the left hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **FmaxIG** | | | | | | |
| **control** | 22.1% | 1.72 | 14.05 | 0.01 | 0.05 | S |
| **experimental** | 26% | 1.76 | | | | |

Table 26: Maximum left hamstring force results (post-test of experimental sample)

Comparison of the maximum strength of the right hamstrings showed significant differences between the pre-test and post-test (sig = 0.01 < α = 0.05).

**2-4-5-According to the results of the right unipodal muscle racio**

| | | | | | | |
|---|---|---|---|---|---|---|
| **RaD** | | | | | | |
| **control** | 14.1% | 5.57 | 2.36 | 0.04 | 0.05 | N/S |
| **experimental** | 8.07% | 5.81 | | | | |

Table 27: Right unipodal muscle racio results (post-test of experimental sample)

Comparison of the maximum strength of the right unipodal muscle racio showed no significant differences between pre- and post-test (sig = 0.93 > α = 0.05).

**2-4-6-According to the results of the left unipodal muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **RaG** | | | | | | |
| **control** | 9.4% | 2.17 | 2.53 | 0.03 | 0.05 | N/S |
| **experimental** | 9.41% | 3.16 | | | | |

Table 28: Left unipodal muscle racio results (post-test of experimental sample)

Comparison of the maximum strength of the left unipodal muscle racio showed no significant differences between pre- and post-test (sig = 0.86 > α = 0.05).

**2-4-7-According to the results of the mixed quadriceps muscle racio**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **MixedRa Q** | | | | | | |
| **control** | 9.57% | 3.17 | 2 | 0.07 | 0.05 | N/S |
| **experimental** | 7.1% | 3.01 | | | | |

Table 29: Right mixed muscle racio results (post-test of the experimental sample)

Comparison of the maximum strength of the quadriceps mixed muscle racio showed no significant differences between pre- and post-test (sig = 0.55 > α = 0.05).

**2-4-8-According to the results of the mixed muscle racio of the hamstrings**

| | x | S | T | sig | α | |
|---|---|---|---|---|---|---|
| **MixedRa I** | | | | | | |
| **control** | 5.29% | 3.22 | 1.6 | 0.14 | 0.05 | N/S |
| **experimental** | 7.63% | 5.11 | | | | |

Table 30: Left mixed muscle racio results (post-test of the experimental sample)

Comparison of the maximum strength of the mixed muscle racio of the hamstrings showed no significant differences between pre-test and post-test (sig = 0.73 > α = 0.05).

**3-Discussion**

For comparison of the pre-test results of the control sample with the experimental sample, the results of age (sig = 2.82 > α = 0.05), weight (sig = 0.15 > α = 0.05) and height (sig = 0.37 > α = 0.05) show no significant difference; the results of the maximum force of the right quadriceps (sig = 0.79 > α = 0.05), the maximum force of the left quadriceps (sig = 0.65 > α = 0.05), the maximum force of the right hamstrings (sig = 0.87 > α = 0.05) and the maximum force of the left hamstrings (sig = 0.76 > α = 0.05) show no significant difference.

The results of right unipodal muscle racio (sig = 0.41 > α = 0.05), left unipodal muscle racio (sig = 0.05 = α = 0.05), mixed quadriceps muscle racio (sig = 0.65 > α = 0.05) and mixed hamstring muscle racio (sig = 0.67 > α = 0.05) ) show no significant difference. For the experimental sample, the right unipodal muscle racio is calculated at 14.19% against a left unipodal muscle racio calculated at 9.4%. There is clearly an asymmetry between right quadriceps and right hamstrings, especially since it is the dominant limb. Concerning the mixed muscular racio of the quadriceps calculated at 9.57% and the mixed muscular racio of the hamstrings calculated at 5.29%, which gives us a slight imbalance at the level of the mixed muscular racio of the quadriceps.

As for the post-test, the comparison of the results of the control sample with those of the experimental sample gives significant differences of the right unipodal muscle race (sig = 0.00 > α = 0.05) in favour of the experimental sample for a balance calculated at 8.07% against a balance calculated at 18.24% for the control sample and significant differences of the left unipodal muscular racio (sig = 0.02 = α = 0.05) in favour of the experimental sample for a 6.41% equilibrium versus a 13.26% equilibrium for the control sample. Regarding the comparison of the mixed muscular racio of the quadriceps of the two populations showed no significant differences (sig = 0.63 > α = 0.05) and a calculated equilibrium of 7.65% for the control sample against a calculated equilibrium of 7.1% for the experimental sample. As expected in our experiment, the development of the maximum force of the quadriceps is neglected. As for the comparison of the mixed muscle racio of the hamstrings of the two populations showed significant differences (sig = 0.63 > α = 0.05) and a calculated equilibrium of 11.44% for the control sample against a calculated equilibrium of 7.63% for the experimental sample.
Regarding the comparison of the results between the pre-test and the post-test of the control sample, the results of the maximum force of the right and left quadriceps showed significant differences between the pre-test and the test station (sig = 0.01 < α = 0.05) and (sig = 0.00 > α = 0.05) with a development of 3.3kg for the right quadriceps and 3.9kg for the left quadriceps. The results of the maximum strength of the right and left hamstrings showed significant differences between the pre-test and the test station (sig = 0.02 < α = 0.05) and (sig = 0.02 < α = 0.05) with a 2kg development for the ischio-straight and 4.1kg for left hamstrings. As for the results of the right unipodal muscle race.

Concerning the comparison of the results between the pre-test and the post-test of the experimental sample, the results of the maximum force of the right and left quadriceps showed significant differences between the pre-test and the test station (sig = 0.01 < α = 0.05) and (sig = 0.00 < α = 0.05) with a development of 3kg for the right quadriceps and 3.5kg for the left quadriceps although they are not supported by a maximum force development program. The results of the maximum strength of the right and left hamstrings showed significant differences between the pre-test and the test station (sig = 0.01 < α = 0.05) and (sig = 0.93 > α = 0.05) with a development of 4.2kg for ischio-hamstringsstraight and 3.9kg for left hamstrings. As for the results of the right and left unipodal muscle race, there are no significant differences (sig = 0.93 > α = 0.05) and (sig = 0.86 > α = 0.05) but a less pronounced imbalance in the post-test of -6.03% right and almost identical +0.01% left. Concerning the results of the quadriceps and hamstrings mixed muscular racio, there are no significant differences (sig = 0.55 > α = 0.05) and (sig = 0.73 > α = 0.05) but a less pronounced imbalance in the postquadriceps test of -2.47% right and more pronounced in the hamstring post-test of +2.42% left.

**3-1-general discussion**

| | Fmax Q/D | Fmax Q/G | F/max H/R | F/max H/L | Racio R | Racio L | MixedRa Q | MixedRa H |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Pré | 27,3 kg | 24.4 kg | 23.3 kg | 21.5 kg | 15.62% | 12.77% | 10.26% | 7.23% |
| Post | 30.6 kg | 28.3 kg | 25.3 kg | 25.4 kg | 18.24% | 13.26% | 7.65% | 11.44% |

Table 31: Results of the maximum strength of the right and left quadriceps, the right and left hamstrings of the right and left unipodal muscular racio, the mixed muscular racio of the quadriceps and hamstrings (pre and post-test control sample)

For the control sample, the maximum force of the right and left quadriceps was calculated in the pre-test at (27.3 kg – 24.4kg) and a mixed muscle racio calculated at 10.26% against a maximum force calculated in the post-test at (30.6 kg – 28.3 kg) and a mixed muscular racio calculated at 7.65%, thus improving the muscular balance of the quadriceps by 2.61%. The maximum force of the right and left hamstrings was calculated in the pre-test at (23.3 kg – 21.5 kg) and a mixed muscle racio calculated at 7.23% against a maximum force calculated in the post-test at (25.3 kg – 25.4 kg) and a mixed muscle racio calculated at 11.44% thus a decrease in muscle balance of hamstrings by 4.21%. This gives us a muscular balance of quadriceps calculated at 7.65% against a muscular balance of hamstrings calculated at 11.44%. On the other hand, in the pre-test, the muscle balance of the quadriceps was calculated at 10.26% against a muscle balance of the hamstrings calculated at 7.23%.

The unipodal muscular racio of the right lower limb was calculated in the pre-test at 15.62% against 18.24% in the post-test so a decrease of 2.62%. As for the unipodal muscular racio of the lower left limb, it was calculated at 9.4% against 9/41% in the post-test thus an improvement of 0.01%. This gives us a right unipodal balance calculated at 8.7% against a left unipodal balance calculated at 9/41%. In contrast, in the pre-test, the right unipodal muscle balance was calculated at 12.77% against a left unipodal muscle balance calculated at 13.26%. As a result, we consider that the sprinters in the control sample are predisposed to various ischio-Hams during the achievement of their sprint performance as long as they keep this level of muscle balance of the lower limbs and do not improve it.

| | Fmax Q/D | Fmax Q/G | F/max H/R | F/max H/L | Racio R | Racio L | MixedRa Q | MixedRa H |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Pré-test | 26kg | 24.3 kg | 23.4 kg | 22.1 kg | 14.1% | 9.4% | 9.57% | 5.29% |
| Post-test | 29 kg | 27.8 kg | 27.6 kg | 26 kg | 8.07% | 9.41% | 7.1% | 7.63% |

Table 31: Results of the maximum force of the right and left quadriceps, the right and left hamstrings of the right and left unipodal muscular racio, the mixed muscular racio of the quadriceps and hamstrings (pre and post-test of the experimental sample)

For the experimental sample, the maximum force of the right and left quadriceps was calculated in the pre-test at (26KG – 24.3kg) and a mixed muscle racio calculated at 9.57% against a maximum force calculated in the post-test at (29KG – 27.8kg) and a mixed muscular racio calculated at 7.1%, thus improving the muscular balance of the quadriceps by 2.47%. Although the quadriceps have not been concerned with the development of the maximum force nevertheless, it emerges that the development of the maximum force of the hamstrings leads to the development of the quadriceps. The maximum force of the right and left hamstrings was calculated in the pre-test at (23.4KG – 22.1kg) and a mixed muscle racio calculated at 5.29% against a maximum force calculated in the post-test at (27.6KG – 26kg) and a mixed muscle racio calculated at 7.63% thus an improvement in muscle balance of hamstrings of 2.34%. This gives us a muscular balance of quadriceps calculated at 7.1% against a muscular balance of hamstrings calculated at 7.63%. On the other hand, in the pre-test, the muscle balance of the quadriceps was calculated at 9.57% against a muscle balance of the hamstrings calculated at 5.29%.

The unipodal muscle race of the right lower limb was calculated in the pre-test at 14.1% against 8.7% in the post-test so an improvement of 6.03%. As for the unipodal muscular racio of the lower left limb, it was calculated at 9.4% against 9/41% in the post-test thus an improvement of 0.01%. This gives us a right unipodal balance calculated at 8.7% against a left unipodal balance calculated at 9/41%. In contrast, in the pre-test, the right unipodal muscle balance was calculated at 9.57% against a left unipodal muscle balance calculated at 5.29%.

The difference in strength between the dominant and non-dominant limbs does not exceed 10%, in the absence of pathology of the musculoskeletal system. It was also shown that a muscle imbalance between the left/right lower limbs could potentially make the subject susceptible to injury. Asymmetry at the threshold of 10-15% or more is considered an additional strain on the weak leg, compromising the athlete's performance and predisposing the athlete to various injuries (Hewit et al, 2012).

The right unipodal muscle racio calculated at 8.07% < 10% against a left unipodal root calculated at 9.41% < 10%. For us, the training program of the maximum strength of the hamstrings has re-established a good balance between the right post-test uni-podal race and the left uni-podal race post-test. a good balance between post-test straight and post-test straight and post-test.

The mixed muscle racio of quadriceps post-test calculated at 7.1% < 10% against a mixed muscle racio of hamstrings calculated at 7.63% < 10%. For us, the training program of the maximum strength of the hamstrings has restored a good balance between the mixed racio muscular quadriceps post-test and the mixed racio muscular of the hamstrings post-test.

As a result, we consider that the sprinters in the experimental sample are not predisposed to various ischio-Legs during the performance of their sprint as long as they maintain or improve this level of muscle balance of the lower limbs.

Conclusion

In this study, we managed to restore the muscular balance of the lower limbs of sprinters under 17 years of age by carrying out a program of development of the maximum strength of the hamstrings without neglecting a good muscular strengthening of the quadriceps. Post-test results for the experimental sample showed a good recovery of the uni-muscular raciopodal between right lower limb and left lower limb and between the balance of the mixed muscular racio of the quadriceps and the balance of the mixed muscular racio of the hamstrings. On the other hand, the post-test results for the control sample showed an imbalance of the uni-podal muscular racio between the lower right and lower left limb and an imbalance of the mixed muscular racio of the quadriceps and the mixed muscular racio of the ischio-ham. They thus present a serious risk of injury to hamstrings.

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