Unilateral Hamstring Muscle Strengthening Exercises Can Improve Hamstring Asymmetry and Increase Jumping Performance in Sub-Elite Badminton Athletes

**Introduction**

Imbalance or Asymmetry is a natural condition in humans, but in the world of sports, excessive asymmetry is considered detrimental because it can interfere with sports performance and increase the risk of injury (Afonso et al., 2022). A significant imbalance between the strength of the right and left hamstring muscles causes the condition of hamstring asymmetry (Mrzygłód et al., 2021). The hamstrings are an important muscle group that flexes the knee, concentrically extends the hips, and participates in tibial rotation (Schache et al., 2013). This muscle group comprises M. Semimembranosus, M. Semitendinosus, and M. Biceps Femoris. The hamstring muscle is a mixed type of muscle consisting of type I, M. Semitendinosus. If there is a pathology, the muscle will experience tension and shortening or contractures, and type II, namely M. Semimembranosus and M. Biceps Femoris, if there is pathology, atrophy will occur, or muscle weakness (Opar, Williams and Shield, 2012). The hamstrings also play a role in the control of knee extension and play an important role in sprint acceleration performance (Ishoi et al., 2019). Meanwhile, less flexible hamstring muscles have been shown to affect posture and cause a posterior tilt of the pelvis (López-Muñarro et al., 2012).

The length of the hamstring muscles is closely related to muscle strength; if a muscle shortens, the muscle strength will also decrease. When the hamstring muscles experience weakness, it will cause injury, especially in activities that involve running, stopping suddenly, or jumping, as in football, basketball, rugby, tennis, running, futsal, and badminton movements (Arnason et al., 2008). Badminton is a sport that uses rackets with short and intermittent multidirectional movements (Phomsoupha and Laflaye, 2015; Sturgess and Newton, 2008). This sport requires players to perform five movements, such as changing direction (Sturgess and Newton, 2008), twisting and stretching (Osi et al., 2009), and lunging (Kuntze, Mansfield and Sellers, 2010) in response to their opponent’s shot. With the shuttle traveling at speeds in the region of 50-70 m/s$^2$ (110-155
he sample is also a sub
n East Java, Indonesia, who has experience
l while rolling the ball towards themselves, lifting
the ball, and the pelvis is lowered. Meanwhile, the single

Other

= et al., 2019). Hamstring muscle

injury and low sports performance

significant imbalance and is associated with a high risk of

studies have also shown the benefits of unilateral training

asymmetry between the legs and improve subsequent

Nilsson, 2020) showing that hamstring asymmetry is important because it

varies by 10% to 15% is considered an early indicator of a

et al., 2016) which is followed by a decrease in ROM in the

hip joint (Bradley and Portas, 2007) and ankles (Gabbe et

Several studies also state that asymmetry that

by 10% to 15% is considered an early indicator of a

significant imbalance and is associated with a high risk of

injury and low sports performance (Risberg et al., 2018;

Vargas et al., 2019).

Material and Methods

Subjects

The research design used was a quasi-experimental

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Vargas et al., 2019).
with your buttocks down toward the ground. This exercise is performed alternately between the right leg and left leg. The sets, repetitions and training intervals are arranged in the exercise program presented in Table 1.

Table 1. Unilateral hamstring strengthening exercise program

<table>
<thead>
<tr>
<th>Week</th>
<th>Exercise</th>
<th>Set</th>
<th>Repetition</th>
<th>Rest/ Sets</th>
<th>Rest/Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single leg bridge (right)</td>
<td>3</td>
<td>16 rep</td>
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<td>5 minutes</td>
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<tr>
<td></td>
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<td>20 rep</td>
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<td>5 minutes</td>
</tr>
</tbody>
</table>

Table 1 shows a unilateral exercise in the form of a Swiss ball hamstring curl and single leg bridge exercise performed alternately on the right and left legs. The training load also increases in both sets and repetitions. This follows the principle of progressive overload training, where the training load given to athletes must be periodically progressively increased (Adrian and Petru, 2021).

**Instrumented Nordic Test and CMJ Test**

After practising 30 times for ten weeks, the research samples underwent a posttest with the same test, namely the Norbord test, to determine the condition of hamstring asymmetry (Cuthbert et al., 2021; Bishop et al., 2022). The Norbord test can measure an athlete’s hamstring strength through a compact sensor, wirelessly and in real-time, developed with high technology. An athlete can be tested with Norbord in about 30 seconds with accurate and reliable results (Opar et al., 2013; Ercan, Kerem and Kunduracioglu, 2019). Before carrying out the Norbord test, participants were allowed to warm up by doing Nordic movements for three trials. Participants then performed the test with a sifter on a platform with their ankles attached to a weight cell. They were instructed to lean forward as slowly as possible while resisting the movement with their hamstring muscles. The device measures the eccentric force exerted by the hamstring muscle complex when the muscle is elongated under a load, as shown in figure 1. During maximal eccentric resistance of the hamstrings, the peak force is measured in Newtons (N) (Chavarro-Nieto et al., 2022). The difference in the right and left leg hamstring strength value is expressed in proportion. This test was carried out two times, namely before the unilateral exercise intervention (pretest) and after the unilateral exercise intervention (posttest). The condition of hamstring asymmetry that was sampled in this study was an asymmetry that was > 10% on the initial test.

Then do the test using a force plate with Counter Movement Jump (CMJ) to determine jump height (Cheah et al., 2017; Heredia-Jimenez and Orantes-Gonzalez, 2020; Gonzalez Vargas & Gallardo Pérez, 2023). The study by Bishop et al., (2017) stated that the jump height test could validly and reliably identify limb asymmetry profiles (Bishop et al., 2017; Ercan, Kerem and Kunduracioglu, 2019). Before carrying out the test, participants were allowed to warm up by doing Nordic movements for three trials. Participants then performed the test with a sifter on a platform with their ankles attached to a weight cell. They were instructed to lean forward as slowly as possible while resisting the movement with their hamstring muscles. The device measures the eccentric force exerted by the hamstring muscle complex when the muscle is elongated under a load, as shown in figure 1. During maximal eccentric resistance of the hamstrings, the peak force is measured in Newtons (N) (Chavarro-Nieto et al., 2022). The difference in the right and left leg hamstring strength value is expressed in proportion. This test was carried out two times, namely before the unilateral exercise intervention (pretest) and after the unilateral exercise intervention (posttest). The condition of hamstring asymmetry that was sampled in this study was an asymmetry that was > 10% on the initial test.
et al., 2017). Participants step on the pre-calibrated force plate while wearing shoes. They were instructed to stand straight for 5 sec, then after the signal “go”, the participants immediately jumped as high as possible and landed in the force plate area. Each participant is given the opportunity three times to do the maximum CMJ test, with a 1-minute rest interval for each test. The highest jump height value used in the research data (Gathercole, Stellingwerff and Sporer, 2015; Mizuguchi et al., 2015; Anicic et al., 2023).

![Figure 1. Norbord test to determine hamstring muscle strength and asymmetry percentage](image1)

![Figure 2. CMJ test to find out the jump height](image2)

**Statistical Analysis**

The data were analyzed using a descriptive test to determine the mean and standard deviation of the asymmetry and jump height values before and after unilateral exercise. Because the number of samples was ≤ 30, the results of the normality test using the Kolmogorov-Smirnov test yielded a sig value of ≤ 0.05, which assumed the data were not normally distributed, the non-parametric Wilcoxon test was performed with a significance level of 5%. The Wilcoxon test was used to compare the initial test results before being given unilateral hamstring muscle strengthening exercises with the final test results after being given unilateral hamstring muscle strengthening exercises for ten weeks. Unilateral hamstring muscle strengthening exercises were declared to have an effect if the Wilcoxon test results stated a value of p ≤ 0.05. Evaluation of effect size using Cohen’s d (Wiriawan et al., 2024). Data analysis was performed using Microsoft Excel 2013 and SPSS 23 version software.

**Results**

This research was conducted on a sample of 23 people who have male sex characteristics with an age range of 16-20 years and have experience practising badminton for more than five years with the sub-elite athlete category in East Java, Indonesia. The results of a descriptive test of the characteristics of the study subjects are described in Table 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>mean±SD (n=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>17.61±1.16</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>63.57±3.04</td>
</tr>
<tr>
<td>Height, cm</td>
<td>168.7±3.51</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>22.48±0.89</td>
</tr>
</tbody>
</table>

| Experience in badminton training, years | 8.04±1.07 |

The results of the mean and standard deviation (SD) of the asymmetry and jump height variables can be seen in Table 3.

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Pretest (n=23)</th>
<th>Posttest (n=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Symmetry (%)</td>
<td>Jump Height (Cm)</td>
<td>Asymmetry (%)</td>
</tr>
<tr>
<td>1</td>
<td>ASEM</td>
<td>22.60</td>
<td>31.90</td>
</tr>
<tr>
<td>2</td>
<td>ASDD</td>
<td>13.90</td>
<td>20.20</td>
</tr>
<tr>
<td>3</td>
<td>AFJ</td>
<td>16.50</td>
<td>20.40</td>
</tr>
<tr>
<td>4</td>
<td>DAPD</td>
<td>17.10</td>
<td>38.30</td>
</tr>
<tr>
<td>5</td>
<td>GR</td>
<td>18.80</td>
<td>33.90</td>
</tr>
<tr>
<td>6</td>
<td>MIR</td>
<td>14.30</td>
<td>36.80</td>
</tr>
<tr>
<td>7</td>
<td>AF</td>
<td>17.60</td>
<td>26.70</td>
</tr>
<tr>
<td>8</td>
<td>BAH</td>
<td>16.30</td>
<td>30.50</td>
</tr>
<tr>
<td>9</td>
<td>CT</td>
<td>19.50</td>
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</tr>
<tr>
<td>10</td>
<td>EAM</td>
<td>17.60</td>
<td>31.90</td>
</tr>
<tr>
<td>11</td>
<td>GFT</td>
<td>16.30</td>
<td>31.40</td>
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<tr>
<td>12</td>
<td>JD</td>
<td>13.00</td>
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<tr>
<td>13</td>
<td>MH</td>
<td>22.90</td>
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<td>17.60</td>
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<td>RE</td>
<td>59.80</td>
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<td>13.90</td>
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<td>15.10</td>
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<tr>
<td>19</td>
<td>APC</td>
<td>27.18</td>
<td>30.30</td>
</tr>
<tr>
<td>20</td>
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<td>19.18</td>
<td>23.50</td>
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<tr>
<td>21</td>
<td>RAE</td>
<td>38.85</td>
<td>39.00</td>
</tr>
<tr>
<td>22</td>
<td>MWS</td>
<td>16.44</td>
<td>34.20</td>
</tr>
<tr>
<td>23</td>
<td>SMR</td>
<td>13.40</td>
<td>24.00</td>
</tr>
<tr>
<td>Mean</td>
<td>20.26</td>
<td>33.06</td>
<td>9.20</td>
</tr>
<tr>
<td>SD</td>
<td>10.25</td>
<td>4.93</td>
<td>3.51</td>
</tr>
</tbody>
</table>

From a total of 41 samples that were tested for hamstring asymmetry and jump height, it was found that 23 athletes had >10% hamstring asymmetry. This condition is quite dangerous because excessive imbalance can result in less than optimal physical agility and leg power performance and can result in future injuries (Bishop et al., 2018; Paterno and Ford, 2010). Twenty-three athletes who experienced hamstring asymmetry > 10% (Phukan et al., 2021) were given hamstring muscle strengthening exercises using the unilateral training method for 30 meetings for ten weeks. The posttest results showed a decrease in the average asymmetry with an average difference of 11.06% and an increase in the average jump height with an average difference of 2.08 cm from the 23 samples measured.

Unilateral exercises as a treatment in this study were carried out with two models, namely the Swiss ball hamstring curl exercise and the single leg bridge. After ten weeks of treatment, a final test was conducted to determine the effect of asymmetry and jump height. The results are
presented in Table 4. Table 4 above shows the results that significantly influence the results of unilateral exercise for 10 weeks on asymmetry and jump height p<0.05.

<table>
<thead>
<tr>
<th>Measurement system</th>
<th>Variable</th>
<th>Assessment</th>
<th>Mean±SD</th>
<th>P-Value</th>
<th>Effect size</th>
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<tr>
<td>Norbord test</td>
<td>Hamstring Asymmetry (%)</td>
<td>Pretest</td>
<td>20.36±10.25</td>
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<td>1.443</td>
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<td>Counter</td>
<td>Jump height (cm)</td>
<td>Posttest</td>
<td>9.30±3.61</td>
<td>0.000</td>
<td>0.447</td>
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</table>

Description: p ≤ 0.001 Significantly different using the Wilcoxon test.

### Discussion

Several studies state that athletes with asymmetrical leg conditions can increase the risk of injury, and skeletal muscle disorders, reduce their sports performance and limit their movements (Bishop et al., 2018; Tucker and Hanley, 2017). Hoffman et al., (2007) stated in their research that an asymmetry of more than 10% could reduce the agility performance of athletes (Hoffman et al., 2007). Meanwhile, Bell et al., (2014) also in their research stated that an asymmetry of more than 10% could reduce jumping performance (Bell et al., 2014). Sports training is often given as a therapy to improve the athlete’s asymmetry, although the improvement is still tiny, and many results are not significant (Bishop, Turner and Read, 2018; Bettariga, Turner, et al., 2022). However, this study has proven that giving unilateral exercises with single-leg bridge movements and Swiss ball Hamstring curls for ten weeks can significantly improve the percentage of hamstring asymmetry. This is in line with the research of Mrzygłód et al., (2021), who stated in their research that soccer training in one season supplemented by a 3-week body weight training program succeeded in reducing gluteal and hamstring imbalances between the legs (Mrzygłód et al., 2021). Studies on soccer players have shown differences in strength and flexibility between dominant and non-dominant limbs in sports movements, giving rise to asymmetry that can cause thigh muscle injuries (Scilingo et al., 2005; Croisier et al., 2008).

The unilateral exercise with the single-leg bridge activates the high hamstrings and gluteals. The knee that bends in the single-leg bridge is considered the dominant hamstring. However, the weakness of the gluteus maximus and medius in high hamstring activation may reduce these exercises’ contribution to gluteal strengthening (Lehecka et al., 2017; Pori et al., 2021). In addition, there is a functional-anatomical relationship between the hamstring muscles and the sacrotuberosus ligament which also impacts trunk stability (Vleeming, Stoeckart and Snijders, 1989). Then in elite soccer players, it is known that hamstring muscle strengthening exercises can affect explosive activities such as short sprint times of 5 m and 10 m and the results of countermovement jumps. This shows that hamstring muscle-strengthening exercises can positively affect other physical performance (Krommes et al., 2017). The Swiss ball Hamstring curl exercise can increase hamstring muscle strength (Monajati et al., 2017; Guruhan et al., 2020). Hamstring and quadriceps muscle strength measured during maximal isometric or isokinetic contractions is usually reported as the limb symmetry index (LSI) (Undheim et al., 2015; Grindem et al., 2016). The Swiss ball Hamstring curl exercise activates the hamstring muscles, including the biceps femoris and semitendinosus, when in an open knee position (Monajati et al., 2017).

This study also stated that jump performance, as expressed by jump height, had increased after doing unilateral hamstring exercises for ten weeks. These results are consistent with research by Bettariga, Maestroni, et al., (2022), which states that unilateral strength and power training in soccer athletes for six weeks can improve jumping and agility results (Bettariga, Maestroni, et al., 2022). Pardos-Mainer et al., (2020) demonstrated improvement in asymmetry by increasing horizontal jump results by providing female soccer athletes with Nordsics, lunges, plyometric and plank exercises for ten weeks (Pardos-Mainer et al., 2020). This shows that the selected strengthening exercises can improve vertical and horizontal jumps (Fitzpatrick, Cimadore and Cleather, 2019; Arede et al., 2022).

Unilateral strength training can increase jumping performance compared to bilateral training (Liao et al., 2022). Several studies by Bogdanis et al., (2019); Makaruk et al., (2011); Stern et al., (2020) also stated that unilateral training was more effective in increasing jumping performance (Makaruk et al., 2011; Bogdanis et al., 2019; Stern et al., 2020). This is because unilateral training can increase muscle strength more than bilateral exercises (Gonzalo-Skok, Tous-Fajardo, Suarez-Arrones, et al., 2017). This also relates to the principle of specific training (Liao et al., 2022). The specific training principle is crucial for specific adaptation to the planned performance improvement targets (Brearley and Bishop, 2019). By the subjects in this study who used badminton athletes, it is known that badminton is a sport that uses one dominant hand used to hit the shuttlecock, which will be followed by one leg movement by shifting lower leg activity from the ipsilateral leg to the contralateral leg faster while increasing the rate of increase in contralateral leg muscle activity (Masu and Nagai, 2016).

Unilateral exercises can improve lower limb stability and effectively improve unilateral squat jump performance and RFDO–50 ms and RFDO–100 ms (strength development rate) in unilateral isometric seated leg extension (Kulas, Windley and Schmitz, 2005; Bogdanis et al., 2019). Electromyographic results of vertical jumps unilaterally are 10–25% higher than bilaterally seen from the vastus intermedius and gastrocnemius muscles (Turki et al., 2011). Unilateral training increases strength and strongly stimulates muscles such as the ankle, knee and hip extensors to produce greater neuromuscular adaptation (Gonzalo-Skok, Tous-Fajardo, Valero-Campo, et al., 2017).
follows the concept of Andersen et al., (2014), who showed a significant increase in unilateral jump height after an 8-week bilateral and unilateral combined strength training program (Andersen et al., 2014).

The ability to jump is regulated and controlled by the central nervous system through coordination of body joints, muscles, and ligaments to achieve optimal explosive force in the lower limb muscle groups, resulting in the most effective jumping technique (Zhang et al., 2023). Unilateral training and bilateral training, following the specific training principle, enhance neuromuscular control for unilateral and bilateral movements, respectively. This is achieved by increasing the recruitment of motor units, the frequency of nerve impulses, and coordination, thereby improving movement performance. Training one limb at a time can clearly affect the neuromuscular adaptation of that specific limb. Bilateral training had beneficial benefits on bilateral motions (Gadea Uribarri et al., 2023). Unilateral training leads to an increase in muscle strength and neural activity on the untrained side, known as the cross-migration effect (Howatson et al., 2013). This increase in strength is linked to a rise in EMG activity, indicating that central neural adaptation plays a crucial role in strength development. The precise process of cross-migration is not fully understood; however, theories suggest it could be linked to brain adaptation, intricate alterations in contralateral motor pathways, and motor learning as postulated (Lee and Carroll, 2007). During cross-migration, there is no notable enlargement in the cross-sectional area of the corresponding muscle on the opposite side. This phenomenon seems to be linked to the adjustment and control of the neuromuscular system by the cerebral cortex and spinal cord, with minimal impact from myogenic factors (Bezerra et al., 2009). There is a strong relationship between motor cortex activity and the impact of training. Unilateral training can improve bilateral muscle strength and potentially decrease inhibitory signals from the trained side to the untrained side of the nervous system. Cross-migration is primarily based on neuromodulation of the brain and spinal cord. Unilateral training triggers activity in the central nerve on the non-training side, which is then transmitted to the motor cortical area on the training side through a conduction pathway. Meanwhile, the motor cortical area on the non-training side is somewhat suppressed. The signal is then sent via the corticospinal tract to the motor neurons in the anterior horn of the spinal cord, leading to sustained excitement in the spinal motor neurons and influencing muscle contraction (Zhang et al., 2023).

Conclusions

Unilateral exercise with two models, namely the Swiss ball hamstring curl exercise and the single leg bridge for ten weeks, can improve hamstring asymmetry, the percentage of which is above 10%. In addition, this unilateral exercise can also increase jumping performance which is expressed in jump height. This study recommends doing hamstring muscle strengthening exercises with a unilateral method so that the risk of high asymmetry is reduced and the possibility of injury to the hamstring and other muscles around the knee is reduced.

Funding

This research was funded by Universitas Negeri Surabaya, East Java, Indonesia.

Conflicts of Interest

The authors declare no conflict of interest.

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