THE IMPACT OF SPEED ON LOWER LIMB CONTROL ASYMMETRY IN TRIPLE EXTENSION MOVEMENT DURING PSYCHO-NEURO-MOTOR TRAINING

Alexandra Reta IACOBINI[1,2] *, Pierre Joseph DE HILLERIN[1]

[1]*Doctoral School of Sports Science and Physical Education, National University of Science and Technology Politehnica Bucharest, Pitești University Center, 110040 Romania*

[2]*Faculty of Physical Education and Sport, Spiru Haret University, 030045 Romania*

** Corresponding author: alexandra.iacobini@spiruharet.ro*

https://doi.org/10.52846/46.2025.1.17

Abstract: *Background.* This study investigates the outcomes of psycho-neuro-motor control training sessions conducted with junior basketball athletes, employing a Conditions Simulator for Water Sports (C.S.N. Simulator). The primary aim of the program was to enhance movement control during the vertical jump and to optimize execution quality. Although symmetry analysis was not a predefined objective, observations revealed modifications in lower-limb symmetry as a result of the psycho-neuro-motor control interventions. Building on our previous findings that control asymmetry in ankle joint extension varies with execution speed, this study further explores the dynamics of symmetry and asymmetry under different motor demands.

Methods. A case study was conducted on a junior basketball athlete, focusing on the emergence of movement symmetries and asymmetries following training with the C.S.N. Simulator. Collected data enabled the assessment of the dynamics of symmetry and asymmetry in the triple extension movement, offering insights into the coordination of both lower limbs under varying performance demands.

Results. Findings indicated that lower-limb control during the triple extension is influenced by execution speed, with evidence of differential adaptations in response to increased velocity demands.

Conclusions. The study highlights new research avenues regarding the dynamics of symmetry and asymmetry in motor control, both in additional movement patterns and across diverse athletic populations. Future investigations extending to upper-limb movements and athletes from other sports disciplines may contribute to the development of training strategies aimed at optimizing asymmetries and, ultimately, enhancing athletic performance.

Keywords: interlimb asymmetry, psycho-neuro-motor control, execution speed, basketball performance

Introduction

In neuroscience, symmetry and asymmetry are closely linked to the brain's hemispheres (Hugdahl, 2005). Corballis argues that the perception of the brain as symmetrical stems from the symmetry of the body's limbs, but this view is inaccurate (Corballis, 2020). Furthermore, Toga & Thompson highlights that the brain's two hemispheres have distinct anatomical functions, with lateralization involving a combination of evolutionary, developmental, and pathological factors (Toga & Thompson, 2003). Hugdahl supports this, emphasizing that despite the appearance of symmetry, brain function is inherently asymmetric (Hugdahl, 2005). A simple example of this is the prevalence of right-handedness, with only 12% of the population being left-handed (Corballis, 2020). Auerbach also observes bilateral asymmetry in humans, noting right-side dominance in the upper limbs and a left-foot preference for the lower limbs (Auerbach, 2006).

Lateralization is common in sports, where dominant sides are often chosen based on individual preferences and the sport's requirements (Maloney, 2019). Castañer emphasizes that lateralization is integral to technical, tactical, and psychological training in athletes (Castañer, 2018). Wang finds that about 90% of people favor their right hand, 80% their right foot, and 70% their right eye (Wang, 2018), with these preferences beginning in childhood (Streri & de Hevia, 2015). Caplan notes that the right hand generally outperforms the left in object handling tasks (Caplan, 1976). Furthermore, Wang suggests left-handed athletes may have an advantage in sports, as they present less common challenges for opponents (Wang, 2018).

In certain sports, such as basketball, ambidexterity is essential for professional athletes (Čvorović, 2012), as it allows for greater flexibility and effectiveness. Krzykała and Croitoru highlight that athletes in unilateral sports often exhibit more pronounced asymmetries between limbs (Krzykała et al., 2023; Croitoru, 1999). Asymmetry levels also differ based on the athlete's training duration, with professional athletes showing more significant asymmetries

(Hart, 2016). Maloney argues that these asymmetries are adaptive but can increase with long-term training (Maloney, 2019), especially in complex movements like shooting (Castañer, 2018).

Functional asymmetry has both positive and negative effects on performance (Khudik, 2018). Training the non-dominant side can reduce asymmetry and improve performance. In basketball, for instance, training both sides ensures more efficient movement execution, making the athlete more unpredictable. Lower limb asymmetry, resulting from strength or power differences between the legs, is influenced by factors like gender, prior injuries, and sport-specific demands (Guan Y, 2021; Cone, 2021).

Our previous studies on ankle joint extension movements revealed that control asymmetry changes with speed. At higher speeds, the non-dominant leg often becomes dominant, possibly due to a preference for the leg opposite the dominant hand, while the dominant leg is favored in slower, strength-based movements. As speed increases, control diminishes, leading to more ballistic and less controlled movements, suggesting that the athlete's control capacity is exceeded (Iacobini, 2025). These findings underscore the need for further research on the relationship between asymmetry and speed to optimize training strategies, enhance athletic performance, and reduce the risk of injury.

Materials and Methods

This study was conducted through the implementation of psycho-neuro-motor control training using the "C.S.N. Simulator for Nautical Sports" (hereinafter referred to as the C.S.N. Simulator), chosen for its ability to adhere to the fundamental principles of simulators, according to Nicu Alexe's theory.

The C.S.N. Simulator represents a specialized system, as described by Angelescu, which integrates a hardware component (including an inertial disk, force sensors, an electromagnetic braking system, and a computer) and a software component (Angelescu, 2014, p. 118). This structure adheres to the five fundamental principles for designing, implementing, and using testing and training equipment, thus facilitating direct interaction between the athlete and the simulator. Through the simulator, the athlete can visualize a graphical model of the movement on the computer screen, with the ability to monitor and control in real time the level of force applied during a specific movement, adjusted for different resistance modes (Angelescu, 2014, p. 118). This process is tailored according to the specific objectives of the training program.

These principles include ensuring precise measurement conditions and providing real-time, relevant information.

The basic principle, "Creating measurement conditions", refers to the fact that in order to measure various parameters such as force, acceleration, speed, displacement, and time, specific transducers are required to continuously or intermittently collect information about these factors (Nicu, 1993). The basic principle, "Instantaneous provision of information", involves equipping the system with capabilities for numerical display of values, visualization of parameter variation curves, optical or acoustic alarms, computers, projection screens, etc. (Nicu, 1993).

The case study focused on an athlete from a performance basketball team in Bucharest, a member of the U16 National Basketball Team, who followed a psycho-neuro-motor training program aimed at improving vertical jump height. The program was conducted on the C.S.N. Simulator during the qualification stage for the higher rounds of the National Championship.

The athlete participated in a five-day consecutive training program on the C.S.N. Simulator, initially focusing on developing control of movements specific to the vertical jump and improving its quality. Within this program, the opportunity arose to analyze patterns associated with the dynamics of asymmetries between the lower limbs, in the context of a symmetrical movement influenced by its execution speed.

Thus, the athlete performed an exercise targeting triple extension movement, *conducted from a lying position on the simulator bench, with the knees pulled to the chest and the simulator's straps attached to the soles of the feet* (as shown in Figure 1). *The exercise involved pushing through the heels simultaneously with leg extension, followed by an explosive movement from the toes achieved through the extension of the foot from the ankle joint.*

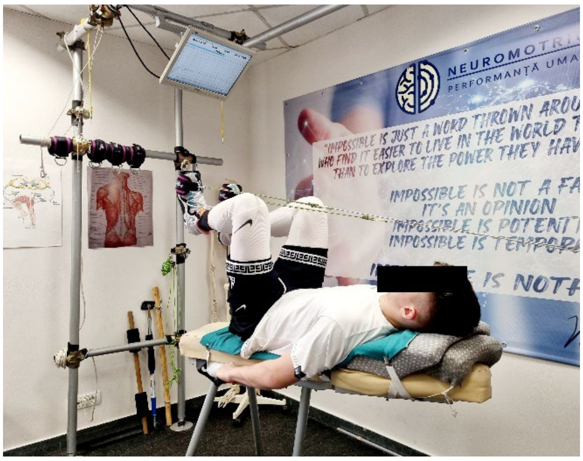

Figure 1. The execution technique of the triple extension exercise

The control load set for the execution of this exercise is 4 daN (equivalent to 4.07 kg-force), which is considered a low force load, as the main objective of the training is to develop control rather than increase strength.

The execution speed of the exercise follows a progressive increase according to a standardized protocol, as follows:

- *Training 1 (T1)*: the athlete performs 150 repetitions alternating leg movements at a low speed, with the simulator's brake intensityset at 90%, that results in an average execution speed of 0.06 m/s.

The C.S.N. simulator is equipped with an electromagnetic braking system. To achieve speed-dependent nonlinear braking, a setup was implemented to link the average intensity of the magnetic field to the speed. At 100% intensity, the magnetic field is continuous, while at lower values, a fluctuating magnetic field is generated, with its intensity expressed as a percentage of the maximum possible value. Consequently, the units representing the selected braking intensity are expressed as percentages relative to the maximum achievable magnetic braking field intensity.

- *Training 2 (T2)*, the exercises involve simultaneous movement of both legs, maintaining the same low speed used previously, resulting in an execution speed of 0.11 m/s.
- *Training 3 (T3)*, the brake intensity is reduced to 50%, which forces the athlete to accelerate the movements to maintain the control load on the pre-established graphical model, thereby creating a perception of increased speed up to an average execution speed of 0.17 m/s.
- *Training 4 (T4)*, the brake intensity is reduced to 30%, requiring faster reactions and further increasing the execution speed to an average of 0.30 m/s.
- *Training 5 (T5),* the brake intensity remains at 30%, but a speed imposed by the simulator's motor is added, set at 0.5 m/s. This setting ensures a minimum execution speed provided by the simulator, so the athlete does not need to exert effort to reach it, but must generate additional force to exceed this value. This context introduces the athlete to an execution framework at higher speeds, amplifying the degree of difficulty and coordination demands, with execution speed reaching an average of 0.55 m/s

Figure 2. Real-time display of the movement curve

To achieve the set tasks, the athlete follows a reference curve displayed on the monitor, as shown in Figure 2, used as a model that supports the development of movement control. Attention is focused on the quick and controlled initiation of the movement, maintaining it according to the preset model, and completing it explosively.

Results

Next, our analysis will focus on the dynamics of symmetries and asymmetries observed during the psycho-neuro-motor control training, correlated with variations in execution speed on the triple extension movement. The observations are based on the data obtained from the implementation of the previously described training program. This analysis aims to highlight the impact of speed on balance and inter-limb coordination, providing a deeper understanding of the motor adaptation processes within the context of specific training.

1. Training 1 (T1), alternate execution at low speed (simulator's brake intensity 90%)

As shown in Figure 3 (where OY axis represents the position, calculated in meters [m], and OX axis represents the force calculated in decanewton [daN]), control of the movement of the two legs, at this low speed (as shown in figure 4, where OY axis represents the position, calculated in meters [m], and OX axis represents the speed, calculated in meters per second [m/s]), in an alternating pattern, is quite symmetrical, both limb's control being very close to the model requested to be followed by the athlete (the red horizontal line set at 4 daN, as imposed by the training protocol). The graphical expression of the relationship between force and position in the movements executed with both legs is relatively symmetrical in all three moments (1.1, in figure 3, representing the beginning of the movement, the first "push" movement from the heels, 2.1, representing the control of the movement as the legs are extending and 3.1, representing the final moment of the movement, the "explosive" part made from the toes, through the extension of the foot from the ankle joint) in the figure, with no significant differences, regarding asymmetries, between them.

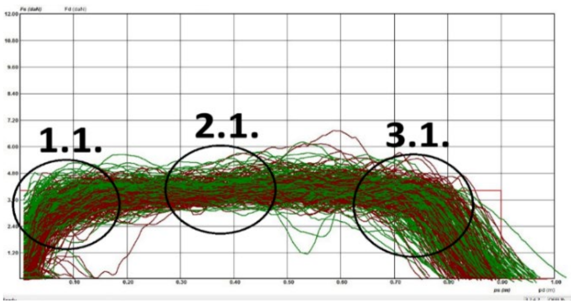

Figure 3. Force in terms of position (T1)

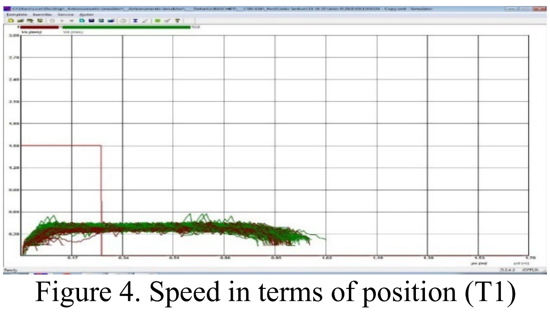
Figure 4. Speed in terms of position (T1)

2. Training 2 (T2), simultaneous execution at low speed (simulator's brake intensity 90%)

As the training progressed to simultaneous execution, with both feet moving at the same time at low speed (as shown in Figure 6), control asymmetry became evident, as it can be seen in Figure 5. The right foot (red lines) is dominant, both at the start of the movement (marked as 1.2 in Figure 5), throughout (moment 2.2 in Figure 5), and at the end (marked as 3.2 in Figure 5). The athlete exceeds the force load requested by the model, which suggests that they were unable to control the movement towards the end, performing what seems to be a "ballistic" motion where their feet actually hit the bench at the end of the movement. In contrast, the left foot (green lines) shows a significantly shorter movement compared to the right foot, and the "explosive" moment at the end of the movement is uncoordinated and slow.

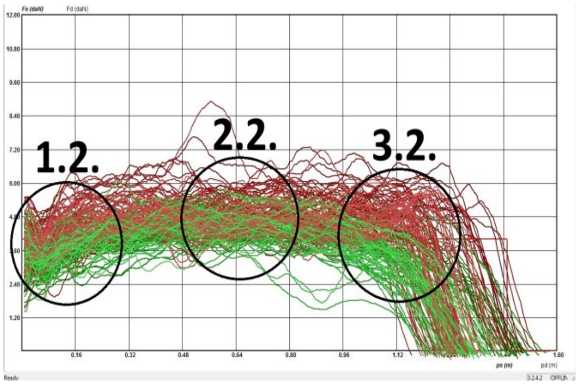

Figure 5. Force in terms of position (T2)

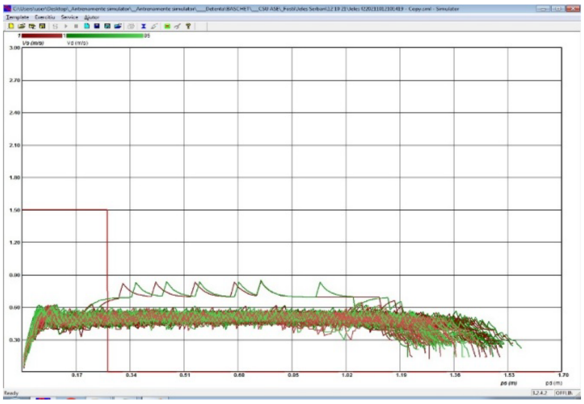

Figure 6. Speed in terms of position (T2)

3. Training 3 (T3), simultaneous movement with 50% simulator's brake intensity, providing the athlete with a sense of increased movement speed

When the simulator's brake intensity is reduced to 50%, leading to an increase in execution speed, as shown in Figure 8, we can observe that the athlete is able to transmit the command to the muscles more quickly on the left leg (the beginning of the movement, marked as 1.3 in Figure 7). The left leg reaches the model almost immediately at the start of the movement, whereas the right leg requires significantly more time to control the movement during the initial phase. This contrasts with the previous day, where, during the slower movement, the command was initiated much more rapidly with the right leg (red lines).

The end of the movement (marked as 3.3 in Figure 7) remains consistent with the previous day, with the right leg being the dominant one, exhibiting an excess of force due to the uncontrolled nature of the movement. However, it is important to highlight that, overall, the movement is much better controlled with both legs compared to the previous day.

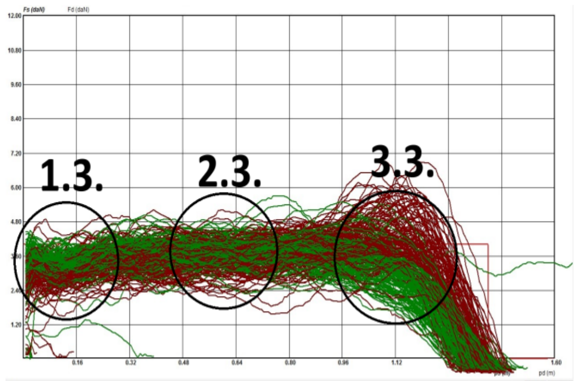

Figure 7. Force in terms of position (T3)

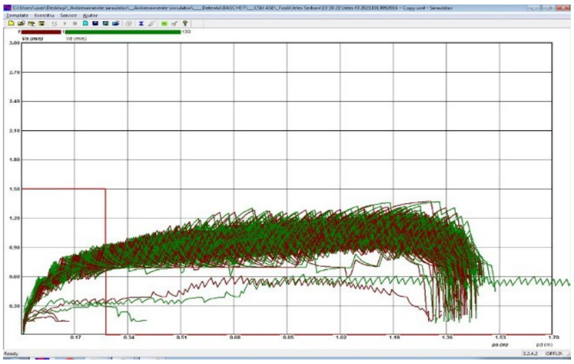

Figure 8. Speed in terms of position (T3)

4. Training 4 (T4), simultaneous movement with 30% simulator's brake intensity, providing the athlete with an even greater sense of increased movement speed.

On the fourth day of training, when the brake intensity is reduced to 30% intensity, leading to an increase in execution speed compared to the previous day, as shown in Figure 10, there is once again a fluctuation in the command at the beginning of the movement compared to the previous day (marked as 1.4 in Figure 9). The right leg executes the control task more quickly; however, interestingly, during the movement (marked as 2.4 in Figure 9), it fails to maintain control with the right leg, showing a drop below the established control force. The left leg (green lines) demonstrates better control of the movement than the right leg (red lines). Nonetheless, at the end of the movement (marked as 3.4 in Figure 9), the athlete returns to the explosive action of the right leg as dominant, though still less controlled, as seen in the previous days.

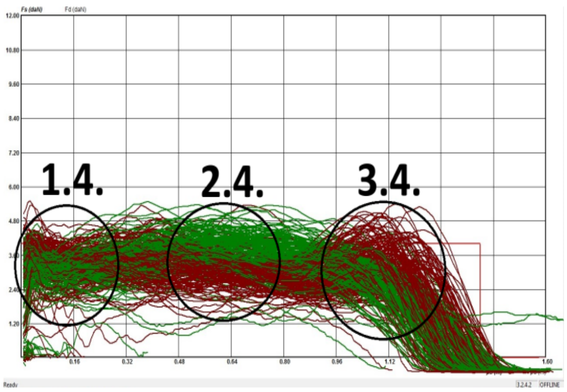

Figure 9. Force in terms of position (T4)

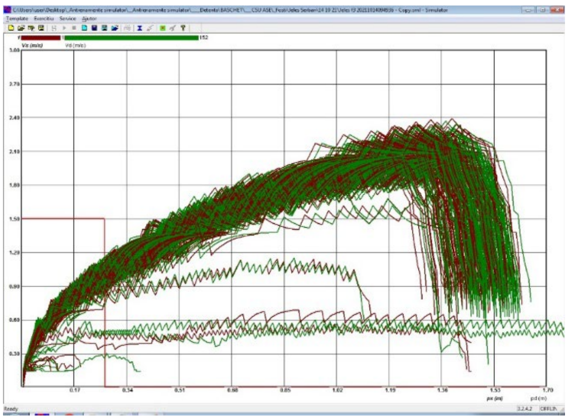

Figure 10. Speed in terms of position (T4)

5. Training 5 (T5), simultaneous movement with 30% brake intensity and a motor speed of 0.5 m/s, providing the athlete with an even greater sense of movement acceleration compared to the previous day.

In the final training session with increased speed, as shown in Figure 12, the simulator's brake intensity was set at 30% and the motor speed was set at 0.5 m/s. The trend observed in the previous session persists, with an even greater lack of control in the left leg (green lines), as visible in Figure 11. There is also a noticeable lack of anticipation in the movement between the start (marked as 1.5 in Figure 11) and the continuation (marked as 2.5 in Figure 11), the fluctuations of control being visible between the limbs, as shown in Figure 11.

Additionally, the end of the movement (marked as 3.5 in Figure 11) reveals an intense asymmetry in control between the two legs, with the left leg entirely lacking the "explosiveness" required for the execution of the movement.

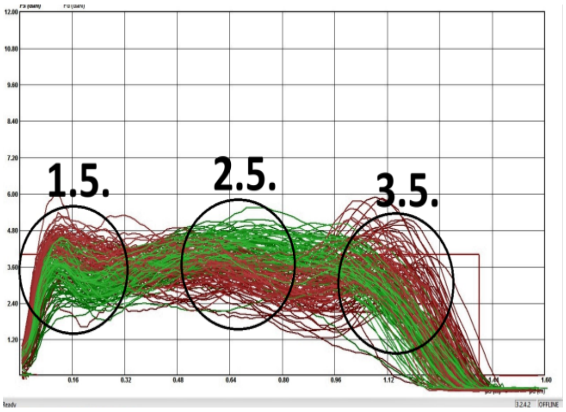

Figure 11. Force in terms of position (T5)

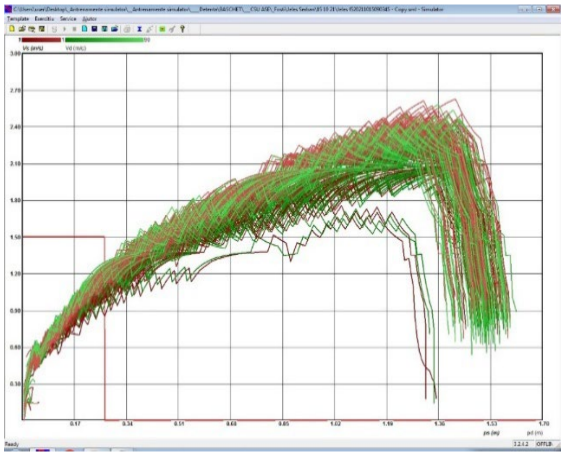
Figure 12. Speed in terms of position (T5)

Discussions

To provide an overview of the symmetry and asymmetry dynamics displayed by the athlete, we have created a graph illustrating their performances during the symmetric load training sessions.

Figure 13 illustrates the differences in force generated by the two lower limbs during symmetric training exercises. Each training session is represented graphically by a distinct color corresponding to a specific combination of speed and simulator brake intensity: blue represents T2, yellow represents T3, green represents T4, and red represents T5. On the graph, the force exerted by the right leg is represented on the OY axis (measured in daN), while the force from the left leg is placed on the OX axis, using the right leg force as a comparative reference. This representation facilitates the visualization and analysis of how the two limbs coordinate and adjust during the training sessions, depending on the gradual increase in speed and reduction of resistance level.

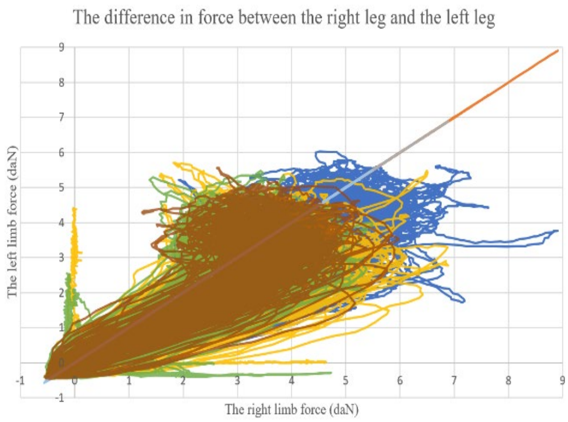

Figure 13. Dynamics of symmetry during the four symmetric training sessions

As observed in Figure 13, the dominance of movement control between the lower limbs changes depending on the working speed. Over the course of the five training days, important changes were noted in the dynamics of movement control and the relationship between the dominant (right) and non-dominant (left) leg. On the first day, at a low speed with alternating movements (brake intensity set to 90%), the athlete demonstrated a balanced control between the two legs, with relatively symmetric movements and no significant differences in force or coordination. However, the transition to simultaneous movements on the second day, while maintaining the same speed and brake intensity conditions, highlighted a clear asymmetry: the dominant right leg exhibited an excess of force, especially towards the end of the movement, indicating a lack of control, while the left leg showed a reduced range of motion and a slower, less explosive execution.

As the execution speed increased by gradually reducing the brake intensity (50% on the third day and 30% on the fourth and fifth days), the athlete showed partial adaptation of control but also fluctuations between the two legs. On the third day, the left leg managed to initiate the movement faster than the right leg, marking an improvement in motor command transmission. However, the end of the movement remained dominated by the excess force of the right leg. On the fourth day, with an even higher speed, the right leg executed the initial task more rapidly but lost control during the movement, while the left leg demonstrated evident progress in stabilizing the movement. On the final day, with an increased motor speed of 0.5 m/s, the asymmetries were amplified: the left leg displayed a lack of anticipation and a decrease in the final explosive phase, while the right leg remained dominant but with a less controlled execution. These results indicate both a progressive adaptation to increasing speed and a persistence of asymmetries in control between the two limbs, particularly under high-intensity and complexity conditions.

Conclusions

Our study focused on the dynamics of symmetry and asymmetry recorded during psycho-neuro-motor control training, correlating these aspects with variations in execution speed. Our observations, based on the data collected through the implementation of the described training program, revealed that with the progressive increase in speed, significant changes occurred in the balance and inter-limb coordination.

Thus, under conditions of low speed and alternating movements, movement control was relatively symmetric, indicating balanced execution. As the athlete transitioned to simultaneous movements and the simulator's brake intensity was reduced, increasing the execution speed, asymmetries became more pronounced. The dominant right leg showed an excess of force, particularly at the end of the movement, while the left leg demonstrated slower and less explosive execution. In the final stages of training, with maximum speeds, the right leg remained dominant but showed a loss of control during the movement, while the left leg exhibited a lack of anticipation and final explosion.

The results underline the significant impact of speed on motor control and inter-limb balance, highlighting the processes of specific adaptation and associated challenges. The analysis of the dynamics of motor symmetries and asymmetries contributes to the optimization of future training programs aimed at improving coordination and balance in movements. These observations have opened new avenues for further research, not only in other exercises and basketball athletes but also in the context of extending the research to upper limbs and athletes from other disciplines. We believe these results provide an important starting point for future studies aimed at optimizing asymmetries in sport, with the goal of enhancing athletic performance.

Conflict of Interest. All authors have equal contributions to this study. All authors have read and agreed to the published version of the manuscript.
Funding: This research received no external funding.
Informed Consent Statement: Informed consent was obtained from the subject involved in the study.
Acknowledgments: The authors would like to express their gratitude to the athlete who voluntarily participated in this study.

References

Angelescu, N., & de Hillerin, P.J. (2014). Improvement of Strength Indicators from the Perspective of Neuromuscular Control Training (PhD thesis). *University of Science and Technology Politehnica Bucharest, Pitești Center*

Auerbach, B.M., Ruff, C.B. (2006). Limb bone bilateral asymmetry: variability and commonality among modern humans. *Journal of Human Evolution*, 50(2), 203-218. https://doi.org/10.1016/j.jhevol.2005.09.004

Caplan, P.J., and Kinsbourne, M. (1976). Baby drops the rattle: asymmetry of duration of grasp by infants. *Child Development*, 2, 532–534. https://doi.org/10.2307/1128815

Castañer, M., Andueza, J., Hileno, R., Puigarnau, S., Prat, Q., Camerino, O. (2018). Profiles of motor laterality in young athletes' performance of complex movements: Merging the MOTORLAT and PATHoops tools. *Frontiers in Psychology*, 9(JUN). https://doi.org/10.3389/fpsyg.2018.00916

Corballis, M.C. (2020). Bilaterally symmetrical: To be or not to be. *Symmetry*, 12(3). https://doi.org/10.3390/sym12030326

Croitoru, D. (1999). Ambidexterity in Sports Games: Examples and Applications in Volleyball. Bucharest: *ANEFS Publishing House.*

Čvorović, A. (2012). The Influence of Basketball on the Asymmetry in the Use of Limbs. *Montenegrin Journal of Sports Science and Medicine*, 1(1), 15-19.

Hart, N.H., Nimphius, S., Weber, J., Spiteri, T., Rantalainen, T., Dobbin, M., Newton, R.U. (2016). Musculoskeletal asymmetry in football athletes: A product of limb function over time. *Medicine and Science in Sports and Exercise* 48: 1379–1387.

Healey, L. A., & Hoogkamer, W. (2022). Longitudinal Bending Stiffness Does Not Affect Running Economy in Nike Vaporfly Shoes. *Journal of Sport and Health Science*, 11(3), 285-292. https://doi.org/10.1016/j.jshs.2021.07.002 .

Hugdahl, K. (2005). Symmetry and asymmetry in the human brain. *European Review*, 13(S2), 119-133. https://doi.org/10.1017/S1062798705000700

Iacobini, A.R., de Hillerin, P.J. (2025). Case study on the dynamics of control asymmetry in ankle joint extension movement during psycho-neuro-motor control training. Ovidius University Annals, Series Physical Education and Sport / Science, movement and health, January 2025, 25 (1): 36-42.

Krzykała, M., Karpowicz, K., Karpowicz, M., Bartkowiak, S., Demuth, A., Czerniak, U., & Janowski, J. (2023). Somatic characteristic, morphological asymmetry and postural stability of youth male canoeists compared to control. A cross-sectional study. *PLOS ONE*, 18(5), e0285997.

Liu, Q., Chen, H., Song, Y., Alla, N., Fekete, G., Li, J., Gu, Y. (2022) Running Velocity and Longitudinal Bending Stiffness Influence the Asymmetry of Kinematic Variables of the Lower Limb Joints. *Bioengineering 9(11):607*. https://doi.org/10.3390/bioengineering9110607

Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C. C., Rosseti, M. B., Carpes, F. P., & Bishop, C. (2019). Do Asymmetry Scores Influence Speed and Power Performance in Elite Female Soccer Players? *Biology of Sport*, 3(36), 209-216. https://doi.org/10.5114/biolsport.2019.85454 .

Maloney, S.J. (2019). The Relationship Between Asymmetry and Athletic Performance: A Critical Review. *Journal of Strength and Conditioning Research*, 33(9), 2579-2593.

Nicu, A. (1993). *Antrenamentul sportiv modern*. Editura Editis, București.

Petrie, B.F., Peters, M. (1980). Handedness: left/right differences in intensity of grasp response and duration of rattle holding in infants. *Infant Behavior and Development*, 3, 215–221. https://doi.org/10.1016/S0163-6383(80)80027-0

Sillamy, N. (1998). Dictionary of Psychology (translation from French). Bucharest: *Univers Enciclopedic Publishing House*.

Streri, A., & de Hevia, M.D. (2015). Manual lateralization in infancy. *Frontiers in Psychology*, 5, 1575. https://doi.org/10.3389/fpsyg.2014.01575

Toga, A.W., Thompson, P.M. (2003). Mapping brain asymmetry. *Nature Reviews Neuroscience*, 4(1), 37-48. https://doi.org/10.1038/nrn1009

Wang, W.-C. (2018). Laterality Preferences in Athletes: Insights from a Database of 1770 Male Athletes. *American Journal of Sports Science*, 6(1). https://doi.org/10.11648/j.ajss.20180601.14