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THE DYNAMICS OF CONTROL ASYMMETRY IN LEG EXTENSION MOVEMENTS DURING PSYCHO-NEURO-MOTOR TRAINING IN YOUTH BASKETBALL ATHLETES

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Abstract: *This study extends our previous research on control asymmetries, now focusing on the leg extension movement in youth basketball athletes using the "conditions simulator for water sports" (C.S.N. Simulator). While the primary goal is improving vertical jump control, the conducted training revealed significant changes in lower limb symmetry and control of the movements. Additionally, fluctuations in strength and lack of anticipation were observed, particularly as execution speed increased. This case study explores symmetries and asymmetries following the C.S.N. simulator training, providing insights into the dynamics of symmetry and anticipation in the leg extension movement. Observations showed that control dominance varied with speed, suggesting adaptations to the training demands. These findings support further research on symmetry dynamics, strength fluctuations, and anticipation in other exercises and sports to optimize athletic performance.*

Key words: *symmetry, asymmetry, psycho-neuro-motor control, basketball*

1. Introduction

To understand control asymmetries, it is essential to examine the fundamentals of psycho-neuro-motor control. The motor system operates at three interconnected levels, relying on optimal feedback control. The spinal cord integrates sensory feedback with descending commands, controlling basic reflexes and locomotor patterns [7], [13]. The brainstem, including the reticular formation and vestibular nuclei, refines postural control and adjusts the speed and quality of movement [13]. The cerebral cortex, which governs planning and execution, processes motor tasks through the primary motor cortex, while the parietal and frontal regions handle motor planning and strategy. Somatosensory information is processed via the somatosensory cortex and cerebellar pathways, with the basal ganglia

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and cerebellum playing key roles in motor function [13].

Schmidt describes the motor control system as a complex network, emphasizing the role of sensory information in shaping movement behavior. Sensation, recorded by sensory organs, is converted into signals sent to the brain, while perception is how the brain interprets these signals. Motor control relies on sensory feedback to regulate movement, providing information about the environment, the body, and their relationship. The author compares this process to a closed-loop system, where feedback drives actions [12]. Marin adds that the quality and quantity of information during movement significantly impact brain activity and movement quality, with more effective information enhancing performance [11].

Regarding asymmetry, individuals tend to favor one side of the body in motor tasks, a phenomenon known as laterality, especially in sports [10]. This preference is influenced by personal choice and the demands of the sport. Also, laterality is closely linked to technical, tactical, and psychological training in athletes [1].

Krzykała observes that athletes adapt to the specific demands of their sport, with unilateral sports particularly highlighting limb asymmetries [9]. Čvorović adds the fact that ambidexterity is crucial for professional basketball players [3]. Asymmetry levels in athletes vary by sport and practice duration, with professional athletes showing greater asymmetries [5]. This is often driven by the habitual use of the dominant side in complex movements, such as shooting in basketball [1].

Khudik discusses the impact of asymmetry on performance, suggesting that training the non-dominant side can reduce asymmetry and enhance performance [8]. In basketball, training both sides ensures effective execution from any position, making athletes more unpredictable.

Lower limb asymmetry, which affects performance, occurs when there is a strength or power difference between the legs, influenced by factors such as gender, injuries, leg length differences, and the emphasis on a dominant limb in certain sports [2], [4].

In our previous research on ankle joint extension movements, we observed that control asymmetry varies with movement speed. The athlete's dominant leg switched roles, with the non-dominant leg becoming dominant during high-speed movements, potentially due to a preference for the leg opposite the dominant hand. In contrast, the dominant leg was used more in slower, strength-based movements. As speed increased, control diminished, leading to more ballistic and uncontrolled movements, indicating that the athlete's capacity for control was exceeded [6]. These findings highlight the need for further research into the dynamics of asymmetry and speed to better understand their interaction. This research could inform the development of more effective training strategies that address asymmetries and optimize lower limb coordination.

2. Objectives of the Study

The purpose of this study is to observe and understand the symmetries and asymmetries in the manifestation of control capacity among youth elite athletes during psycho-neuro-motor control training sessions. This research focuses on analyzing how athletes respond to varying training conditions, particularly in relation to execution speed and the intensity of these conditions.

3. Materials and Methods

The study was conducted on a youth basketball player, part of the National Basketball Team (U16), using the "C.S.N. Simulator for Water Sports" (hereafter referred to as the C.S.N. Simulator), which provides precise measurement conditions and real-time feedback. This simulator is based on controlled movements, which differ from "ballistic movements[4]" in that they require heightened attention from the athlete. These movements are more "conscious" and are controlled throughout their execution, aiming to refine coordination and enhance motor control by focusing on psycho-neuro-motor development.

The athlete underwent a 5-day consecutive training program using the C.S.N. Simulator, initially aimed at enhancing control over the components of the vertical jump movement and improving its quality. This training program provided an opportunity to observe patterns related to the dynamics of asymmetry between the lower limbs during symmetric movements, with a focus on the variation in execution speed.

The 5 training sessions were conducted over five consecutive days, focusing on three exercises aimed at developing vertical jump skills. This study examines the leg extension exercise targeting the knee joint and thigh musculature, performed from a seated position on the simulator bench with feet placed on either side. The cables were attached to the dorsal side of the ankle joint, and the movement involved a forward and upward thrust of the legs. The force load was set at 4 daN (4.07 kg-force), emphasizing movement control over strength enhancement.

Throughout the 5 days, the execution speed progressively increased:

Training day 1 (T1): The athlete alternated leg movements at a slow pace with the brake intensity set to 90%, allowing time to learn the control load. 75 repetitions per leg were completed.

Training day 2 (T2): The brake remained at 90%, and simultaneous leg movements were introduced, requiring control of both legs while maintaining the established movement model.

Training day 3 (T3): The brake intensity was reduced to 50%, and speed increased, with the athlete needing to accelerate movement while maintaining control.

Training day 4 (T4): The brake intensity was reduced further to 30%, and the athlete had to increase movement speed and maintain control.

Training day 5 (T5): The brake stayed at 30%, and a motor speed of 0.5 m/s was added (the simulator's motor provided a minimum speed, for which the athlete did not exert additional effort to achieve), requiring the athlete to generate force beyond the motor's minimum speed, executing movements at higher speeds.

This structured increase in speed and intensity aimed to challenge the athlete's ability to maintain control and adjust to faster execution, providing insights into how speed affects asymmetry dynamics in lower limb movements.

[4] We refer to "ballistic movements" as those in which, from the moment the movement command is initiated, the motion remains unchanged until its completion. In contrast, a "controlled movement" allows for intentional modifications to occur during the development (trajectory) of the movement.

4. Results

Our analysis now shifts to exploring the dynamics of symmetries and asymmetries observed during psycho-neuro-motor control training, with a focus on how variations in execution speed affect the exercise targeting the knee joint and quadriceps musculature, known also as leg extensions exercise. The findings are based on data collected from the implementation of the training program described earlier. This analysis seeks to elucidate the influence of speed on balance and inter-limb coordination, offering a more comprehensive understanding of motor adaptation processes within the specific training context.

4.1. Training Day 1 (T1) – Execution with alternate leg movements, with the simulator's brake intensity set at 90%

In the first day of training, the movement was executed alternately with each leg at a reduced speed, as depicted in figure 1, where the OY axis represents position (in meters [m]) and the OX axis represents speed (in meters per second [m/s]). The simulator's brake intensity was set at 90%, resulting in an average execution speed of 0.12 m/s, with the control load calibrated to 4 daN, equivalent to 4.07 kg-force.

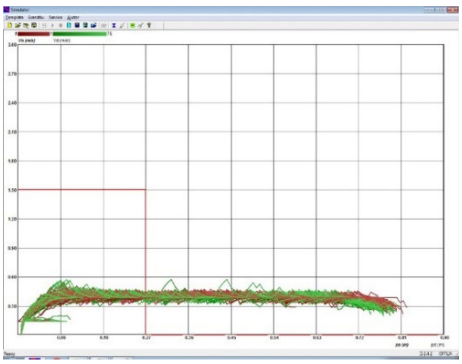

Fig. 1. *Speed in terms of position T1*

As illustrated in figure 2, where the OY axis represents position (measured in meters [m]) and the OX axis represents force (measured in decanewtons [daN]), the athlete exhibited variable movement initiation (denoted as 1.1 in figure 2), with the control load being attained only at the midpoint of the movement (denoted as 2.1 in figure 2). The right leg (indicated by the red lines) was predominantly engaged, both in terms of force generation and its alignment with the control load, particularly toward the end of the movement (denoted as 3.1 in figure 2). A notable disparity in the movement amplitude between the two limbs is also evident.

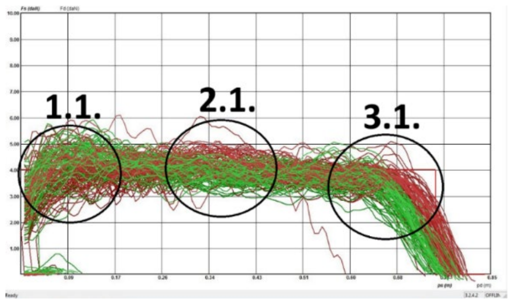

Fig. 2. *Force in terms of position T1*

4.2. Training Day 2 (T2) – Execution with simultaneous leg movements, with the simulator's brake intensity set at 90%

With the transition to simultaneous movement with both legs, still at a low speed (the simulator's brake intensity remains set at 90%, resulting in an average execution speed of 0.29 m/s, as shown in figure 3), it becomes evident that the athlete faces difficulty in commanding both muscles groups simultaneously.

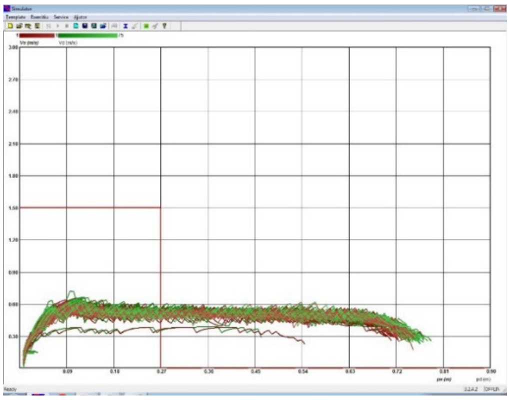

Fig. 3. *Speed in terms of position T2*

The initiation of the movement is relatively slow (denoted as 1.2 in Figure 4), followed by an exaggerated thrust of the legs forward, with the athlete failing to control the movement in the plateau phase (denoted as 2.2 in Figure 4). This initial discrepancy can be attributed to a lack of anticipation regarding the next phase of the movement and the chaining of its sequences. The movement's conclusion is notably asymmetric (denoted as 3.2 in figure 4), with the right leg (displayed with red lines in figure 4) exhibiting excessive force (as visible in figure 5), deviating from the required control model, while the left leg (displayed with green lines in figure 4) lacks the necessary "explosiveness" at the end of the movement (as visible in figure 5), failing to control the movement until its completion.

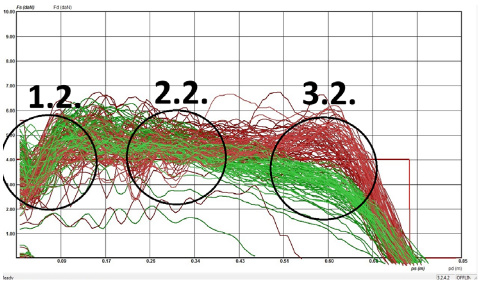

Fig. 4. *Force in terms of position T2*

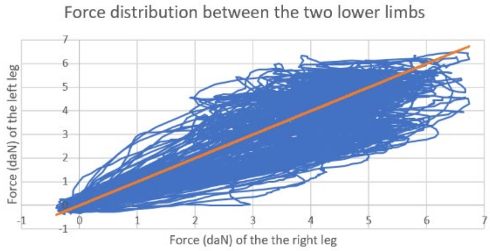

Fig. 5. *Force distribution T2*

4.3. Training Day 3 (T3) – Execution with simultaneous leg movements, with the simulator's brake intensity set at 50%

On the third day, the execution speed increases, as shown in figure 6, with the simulator's brake intensity reduced to 50%, resulting in an average execution speed of 0.37 m/s, while maintaining simultaneous leg movement.

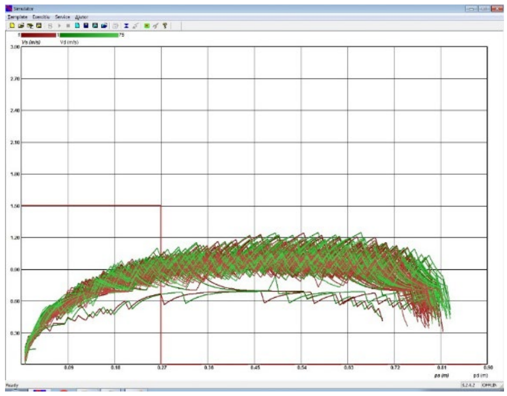

Fig. 6. *Speed in terms of position T3*

A change in control is observed at the beginning of the movement (denoted as 1.3 in Figure 7), compared to the previous day. As speed increases, asymmetry and the lack of anticipation of the movement decrease. Consequently, the right leg (illustrated with red lines in Figure 7) begins to approach the control load, with the "ballistic" movement also diminishing (at moment 2.3 in Figure 7 and visible in Figure 8), while the left leg (illustrated with green lines in figure 7) begins to exhibit "explosiveness" toward the end of the movement (denoted as 3.3 in figure 7 and visible in figure 8). However, asymmetry still persists, with the right leg remaining slightly dominant even at this speed.

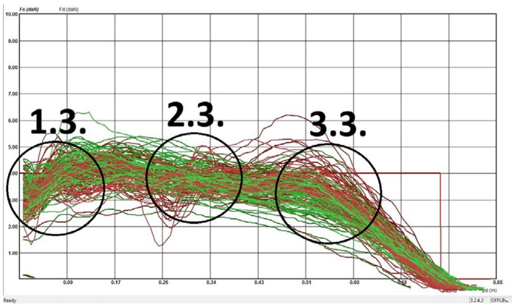

Fig. 7. *Force in terms of position T3*

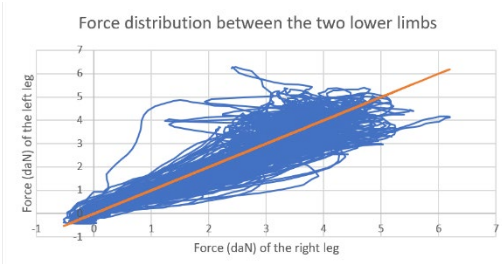

Fig. 8. *Force distribution T3*

4.4. Training Day 4 (T4) – Execution with simultaneous leg movements, with the simulator's brake intensity set at 30%.

On the fourth day, the execution speed increases again, with the simulator's brake reduced to 30%, resulting in an average execution speed of 0.50 m/s, as shown in Figure 9.

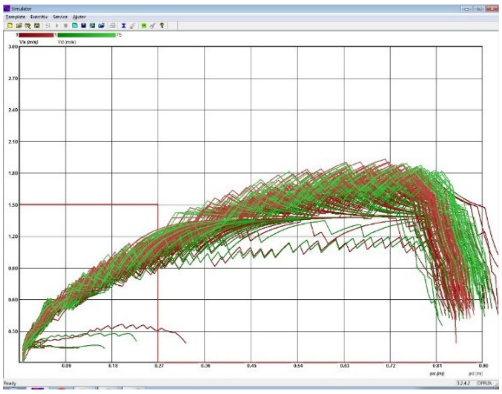

Fig. 9. *Speed in terms of position T4*

This increase in speed leads to fluctuations in control during the initial phase of the movement (denoted as 1.4 in figure 10). The athlete fails to anticipate and control the movement throughout its entirety (moment 2.4 in figure 10), resulting in visible "waves". The conclusion of the movement is intensely asymmetric (denoted as 3.4 in Figure 10), with the right leg (marked with red lines) being dominant, both in terms of force magnitude (as visible also in figure 11) and control quality, while the left leg lacks the necessary "explosiveness".

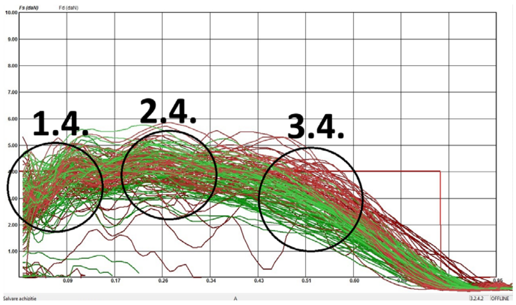

Fig. 10. *Force in terms of position T4*

Fig. 11*. Force distribution T4*

4.5. Training Day 5 (T5) – Execution with simultaneous leg movements, with the simulator's brake intensity set at 30% and simulator's engine speed raised to 0.5 m/s.

In the fifth training session, performed at an increased speed, as shown in Fig. 12 (with the simulator's brake intensity set at 30% and a motor speed of 0.5 m/s, resulting in an average execution speed of 0.60 m/s), the lack of anticipation of the subsequent phase of the movement becomes more pronounced.

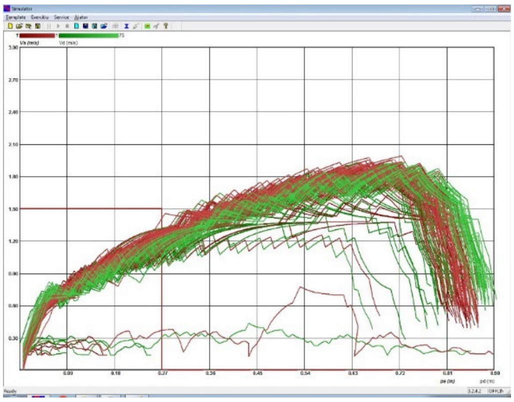

Fig. 12*. Speed in terms of position T5*

The command to the muscles is initiated much more slowly from the beginning of the movement (denoted as 1.5 in figure 13), and this trend continues into the plateau phase (denoted as 2.5 in figure 13). However, what is interesting is that at this speed, a pronounced asymmetry between the movements of the two limbs is no longer visible at the end of the movement (denoted as 3.5 in figure 13). It is important to note, though, that both legs still lack the necessary "explosiveness", leaving room for improvement in refining control and enhancing performance within the movement.

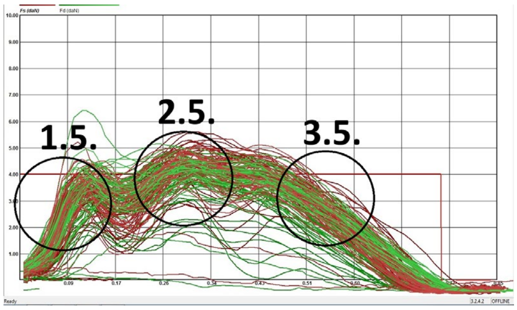

Fig. 13. *Force in terms of position T5*

It is also worth noting that the maximum forces executed by the athlete in the fifth training session of this exercise are significantly lower than those in previous ones (as visible in figure 14), suggesting a lack of strength at high speed for the subject. This also points to the potential development of a system for identifying energy asymmetries (force, speed, power) as a diagnostic tool for psycho-neuro-motor evaluation and the individualized segmentation of athletic training.

Fig. 14*. Force distribution T5*

To present an overview of the dynamics of symmetry and asymmetry exhibited by the athlete, a graph has been constructed to illustrate performance data from the symmetric load training sessions. Figure 15 depicts the differences in force generated by the two lower limbs during these symmetric exercises. Each training session is represented by a distinct color, correlating to a specific combination of speed and simulator brake intensity as follows: *blue* represents T2, *yellow* represents T3, *green* represents T4 and *red* represents T5.

In the graph, the force exerted by the right leg is represented along the Y-axis (measured in daN), while the force generated by the left leg is plotted on the X-axis, using the right leg's force as a comparative reference. This visualization allows for a detailed analysis of the coordination and adjustments made by the two limbs throughout the training sessions, as they respond to the gradual increase in speed and the reduction in resistance.

Fig. 15. *Force distribution T2-T5*

The athlete encountered difficulties in simultaneously activating the muscles of both legs, with the initiation of the movement being notably slow, followed by an exaggerated forward thrust of the legs, resulting in a lack of control over the movement. Furthermore, as illustrated in figure 15, there is a considerable asymmetry in relation to the working speed across different training sessions. At higher speeds (in the final training session – T5), the athlete was unable to approach the target load.

An additional observation is that, with the increase in speed, the force manifestation showed a significant decline, likely due to a misalignment between the command and the execution speed of the exercise.

5. Conclusions

The results of the five training sessions examining the dynamics of symmetry and asymmetry during the leg extension exercise highlight the significant influence of speed on inter-limb coordination and motor adaptation. The gradual increase in execution speed throughout the training sessions revealed important trends in asymmetry between the two limbs, as well as changes in force generation and control.

On Training Day 1 (T1), the athlete demonstrated a marked asymmetry, with the right leg predominantly driving the movement. The slow execution speed and high resistance led to a lack of synchronization between the two limbs, resulting in a reduced capacity to control the movement effectively. However, as speed increased on subsequent days, asymmetry was gradually reduced, with the left leg starting to engage more efficiently during the movements (T3 and T4). On Day 3 (T3), the reduction in brake intensity and the increase in speed resulted in decreased asymmetry, with both limbs working more cohesively, although the right leg remained slightly dominant. On Training Day 4 (T4), with further increases in speed, fluctuations in control were observed, particularly during the initial phases of the movement. These fluctuations led to visible “waves” in the force distribution, indicating that the athlete still faced challenges in anticipating the next phase of the movement at higher speeds. Despite this, the athlete showed improvement in the use of both legs, with the right leg continuing to dominate in terms of force and control quality. By the fifth training session (T5), although a pronounced asymmetry between the limbs was no longer visible at the end of the movement, both legs still lacked the required “explosiveness” to fully control the movement. This highlights the need for further refinement in motor control and performance at higher speeds.

Additionally, the reduced maximum forces generated during T5 suggest a potential issue with strength at high speeds, pointing to the necessity for individualized training strategies that address these limitations.

The findings from this study are highly relevant for basketball athletes, where optimal inter-limb coordination and control are essential for performance and injury prevention. Basketball requires rapid, explosive movements, such as jumping, sprinting, and lateral agility. Improved coordination between both legs, as observed on Training Days 3 and 4, is crucial for these actions, helping athletes perform more efficiently in key movements like jumping for rebounds, shooting, and defending.

However, the persistence of asymmetry on Training Day 5 suggests that further refinement is needed, particularly in developing the “explosiveness” required for high-speed actions. Decreased force generation at higher speeds, as seen on Day 5, could hinder an athlete’s ability to execute powerful movements, such as sprinting or jumping.

Identifying and addressing energy asymmetries (force, speed, power) through diagnostic tools can enable more individualized training plans for basketball players. By targeting specific weaknesses, athletes can improve leg coordination, strength, and explosiveness, leading to better performance and reduced injury risks. In summary, reducing asymmetry and improving strength and control at higher speeds are essential for optimizing basketball performance and preventing injuries.

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