



# Module 3. Application of Inertial Systems (IMU) in Tests for Indoor Team Sports.



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☰ References

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This module will present a set of tests using inertial technology (IMU) to assess, monitor, and evaluate the training process, as well as the conditional and bioenergetic structures at different points in a season, throughout the entire season, or during an athlete's career. These tests provide insights into the player's various systems, allowing for the detection of their progress and any potential functional changes. This helps make decisions on actions that could enhance performance, focusing primarily on the player's conditional and bioenergetic structures.

It's important to note that tracking the load from each training session and/or match using local positioning systems (LPS) on the court, combined with IMU systems, functions as a daily test that complements the tests proposed in this module.

As mentioned earlier, players in any indoor team sport can be monitored and evaluated on the court during training or competition, but they can also be assessed in less specific and decontextualized situations, given the complexity of gameplay. For instance, we can gather data to support and aid in the design of strength programs, primarily used in coadjuvant training and sometimes in optimizing training. This also helps with decision-making during key moments.

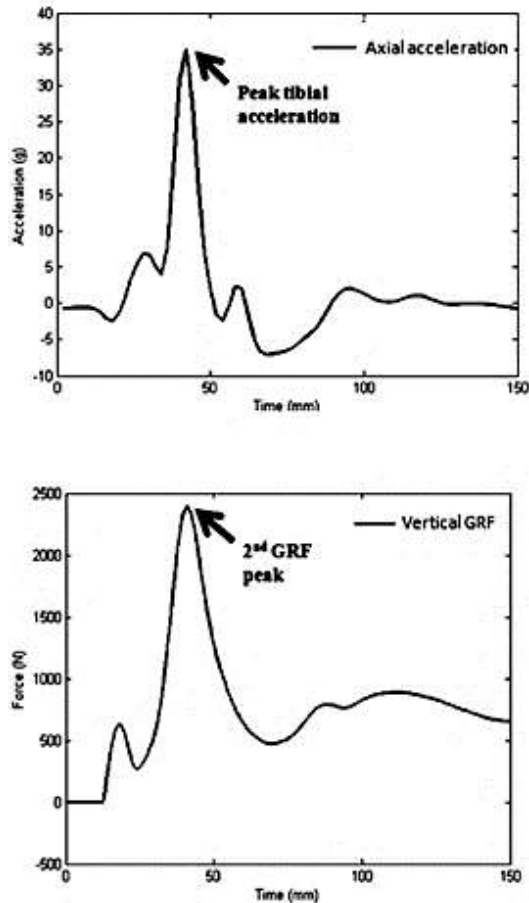
Parameters that can be indirectly measured or estimated using IMU technology include proprioception, fatigue, core stability, strength and power, centripetal force, range of motion, neuromuscular control, and conditioning levels. As noted in earlier modules, while this approach may seem somewhat analytical and reductionist, it is currently one of the best ways to obtain practical information about these two structures. This information can also be supplemented with other types of tests, whether using different technologies or none at all.

For a clearer understanding and interpretation of the data gathered, the assessment, monitoring, and evaluation processes should involve the coaching team, medical team, physical trainer, and, of course, the player, who plays an active role.

To trust the data provided by these measurement systems, it is crucial to determine the validity and reproducibility of both the systems and the tests performed. For example, vertical jumps are validated using force platforms, which measure both the takeoff and landing phases. In this case, the force platform is considered the gold standard. This is how we know IMU systems for this type of test are valid.

To demonstrate the validity of these devices, Lam et al. (2015) compared the ground reaction force produced during a drop jump, using a force platform to measure the peak tibial acceleration recorded by an IMU system during the landing phase from a certain height. Figure 1 shows that both systems exhibit very similar behavior.

Figure 1: Comparison of a vertical jump recorded on a force platform and with an inertial system (IMU)



Source: Lam et al., 2015, <https://goo.su/YPit3jE>

The authors concluded that the inertial system is effective in measuring the impact forces during landing from a jump. This is especially relevant, considering how crucial these movements are in indoor sports like basketball and handball, for example.

Monitoring the load from each training session and/or match using local positioning systems (LPS) on the court, combined with IMU systems, functions as...

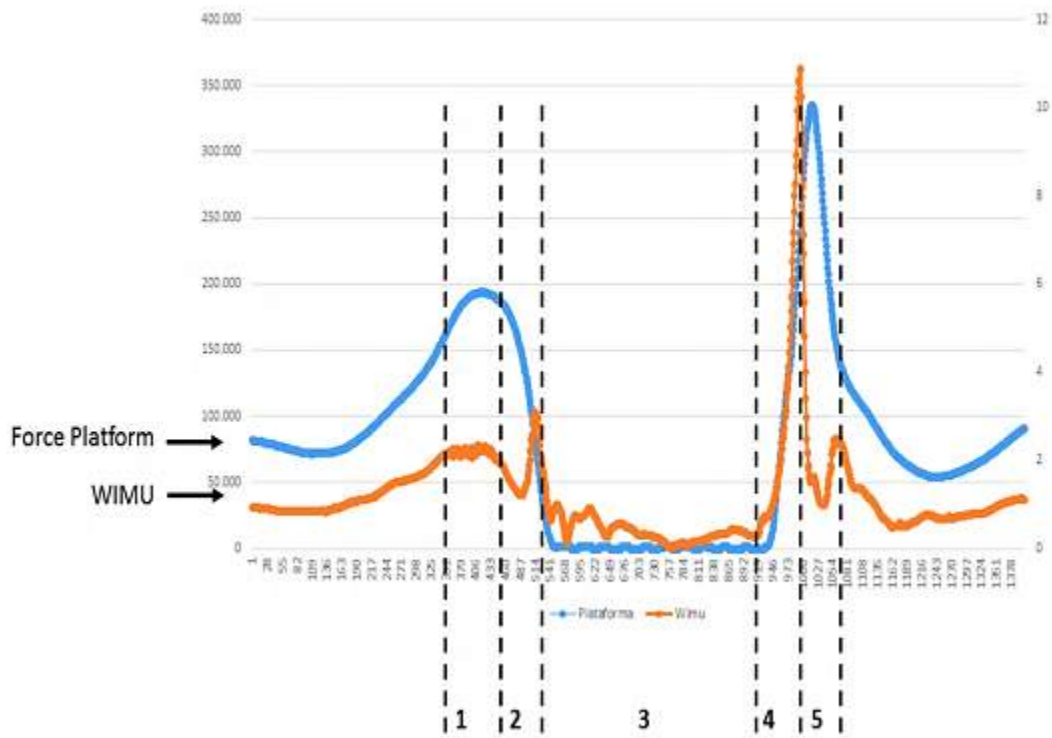
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- A reductionist approach to training that distances itself from the actual competition.
- A dynamic that complicates the accurate quantification of training loads.
- A complementary daily test

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In another scientific study, Pino-Ortega et al. (2018) analyzed the performance of a countermovement jump (CMJ) measured by an inertial system, comparing the results with those obtained from a force platform, considered the gold standard (figure 2).

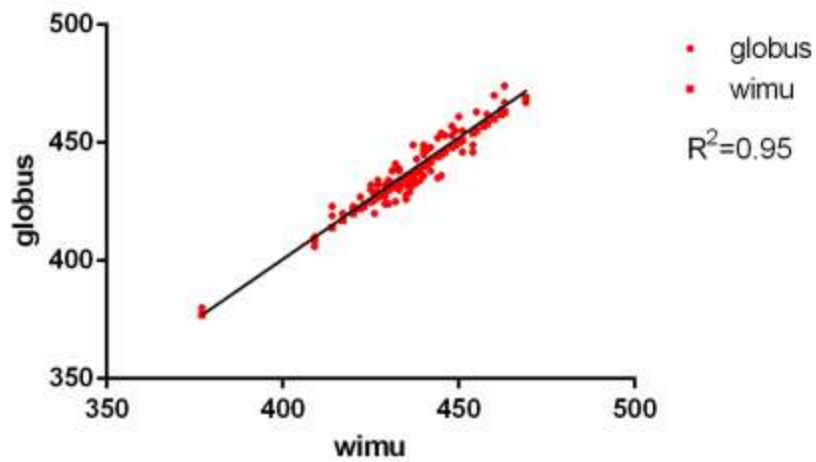
**Figure 2: Comparison of a countermovement jump recorded on a force platform and with an inertial device**



Source: Pino-Ortega et al., 2018, <https://goo.su/HWt1>

Both systems display similar dynamics or curves in their measurements. The correlation between the data from both systems is nearly perfect, with a coefficient of 0.95, as shown in figure 3.

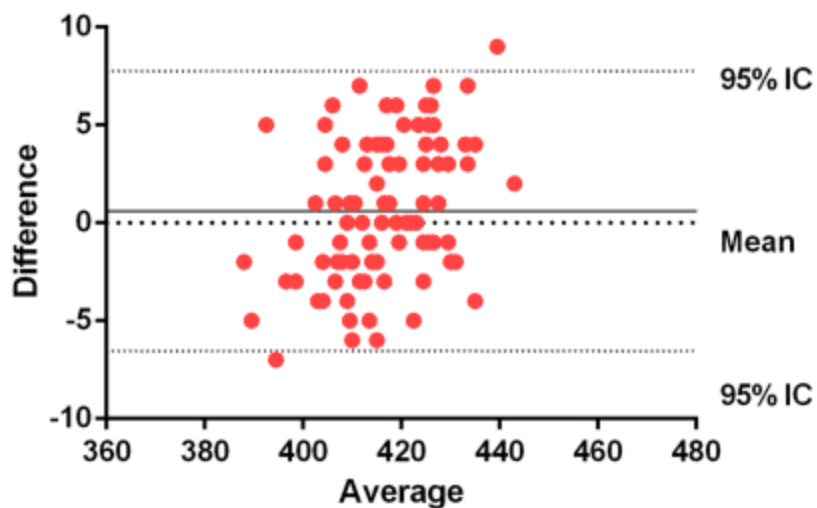
**Figure 3: Correlation graph between inertial devices and a force platform in the evaluation of the vertical jump**



Source: Pino-Ortega et al., 2018, <https://goo.su/HWt1>

Figure 4 shows a Bland-Altman statistical analysis, confirming the reproducibility of the countermovement jump test.

**Figure 4: Reproducibility graph for the countermovement jump test, measured with an inertial device**

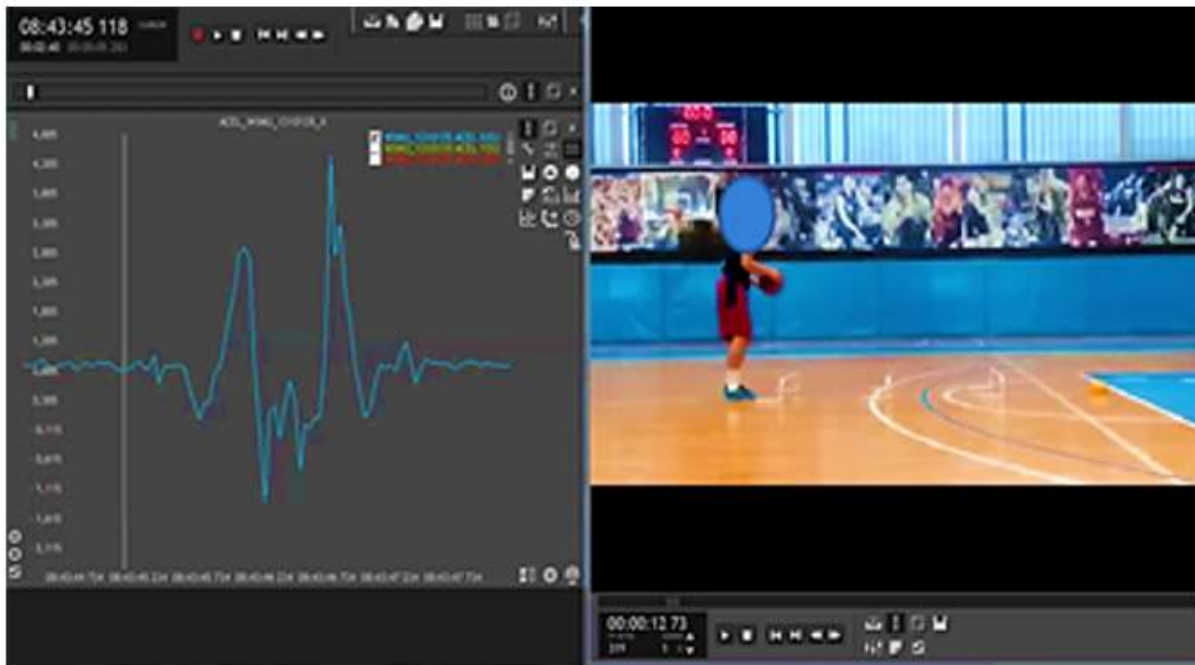


This confirms that the inertial system tested is valid and reproducible for measuring the CMJ.

The following figure illustrates the practical application of a jump test measured with an inertial device on a basketball court, specifically to assess the landing after a jump shot. The image captures the dynamics of the jump performed by the player during the execution of a jump shot. The phases of takeoff, airtime, and landing are clearly visible, represented by the blue line.

A conditioning factor is added to the test, following Newell's 1986 model, to influence the execution of the jump. By placing hurdles on the floor, the player is forced to clear a specific height, which increases the intensity of the takeoff phase and, subsequently, the landing phase.

**Figure 5: Live jump dynamics measured using an inertial device**



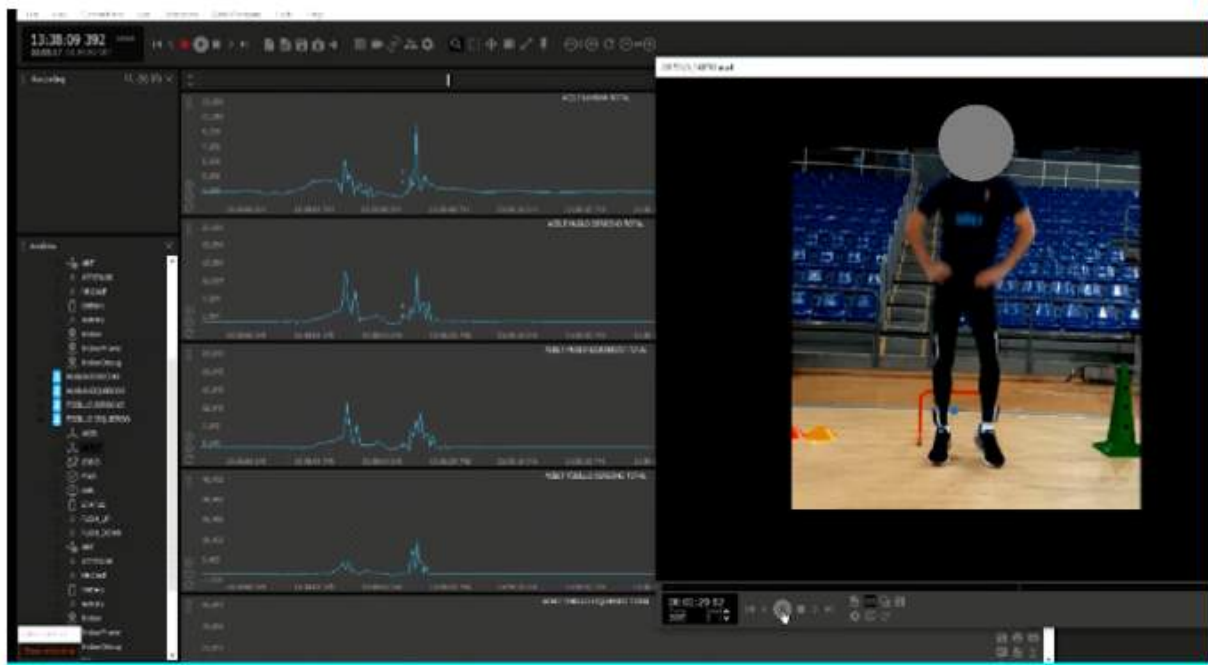
Source: Adapted from WIMU devices (Realtrack Systems S.L.)

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Beyond measuring jump height, which can be important in some situations, these devices provide a key function that we consider valuable in different areas, including player development, high-performance training, or recovery after an injury. This function involves providing live feedback on jumps, which is especially helpful for controlling and assessing landings. This evaluation allows for the optimization of player movements during high-impact actions, such as those frequently performed in sports like handball and basketball. The magnitude of these impacts can also be related to the risk of injury.

The next section presents an alternative for a more detailed analysis of a jump performed over a hurdle. In this case, multiple inertial devices are attached to various anatomical areas of the body (ankle, knee, lower back, and upper back). The person performs the jump, and the devices track acceleration and impact in each of the areas where they are attached (Figure 6).

**Figure 6: Kinetic and kinematic analysis of a jump with inertial devices placed on different body parts**

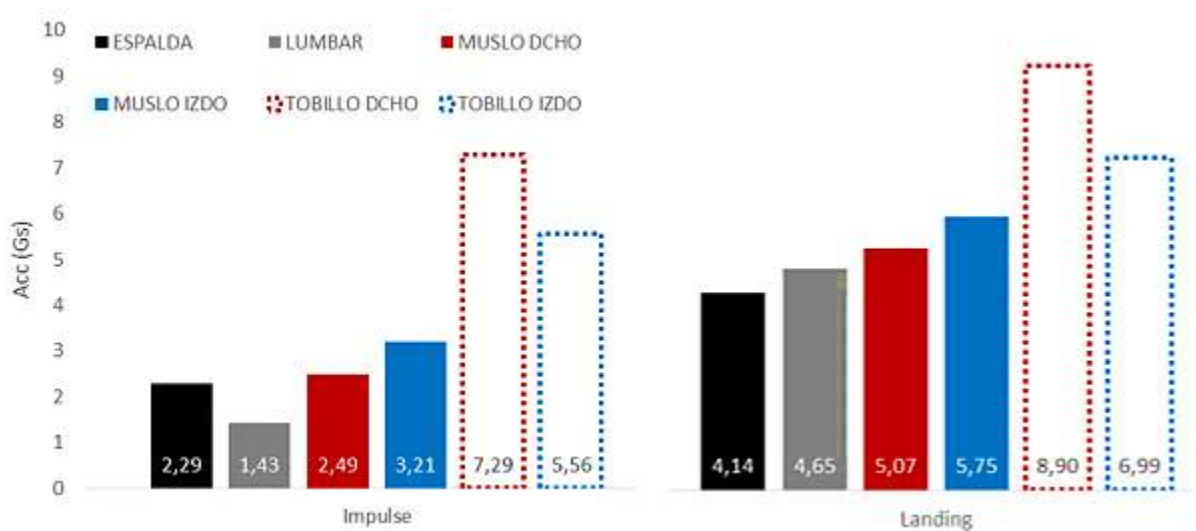


Source: Adapted from WIMU devices (Realtrack Systems S.L.)

The following figure summarizes the dynamics of this jump, as recorded by the sensors located on the indicated anatomical areas.

This method provides data on the acceleration, measured in G, experienced by each area. Notably, the ankle bears the most load during both the takeoff and landing phases. This analysis also highlights differences or asymmetries between both limbs and phases of the jump (takeoff and landing).

**Figure 7: Acceleration of a jump measured with inertial devices placed on different body parts**



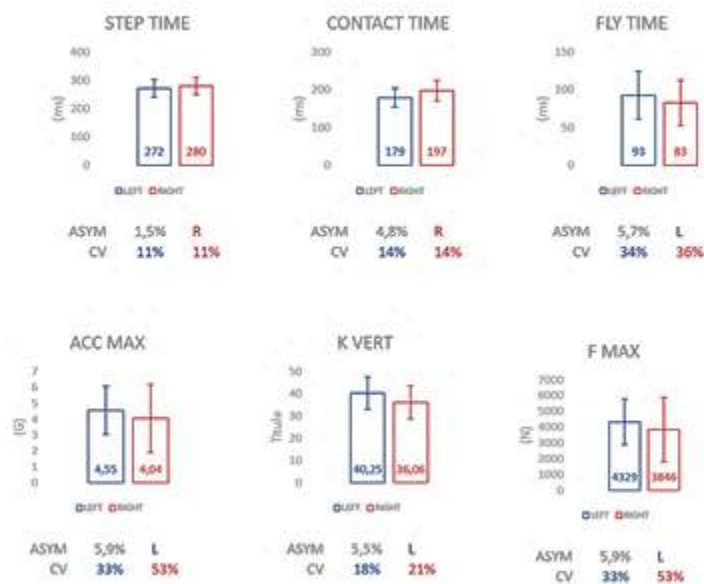
BACK	LOWER BACK	RIGHT THIGH
LEFT THIGH	RIGHT ANKLE	LEFT ANKLE

Source: Original work

In addition, these systems can analyze the impact during each step of a run. Scientific evidence supports the validity and reproducibility of this type of analysis using IMU technology (Gómez-Carmona et al., 2020).

Based on the previous study, the following figure provides an analysis report of impacts during a linear sprint.

**Figure 8: Results of a linear sprint measured with inertial devices (IMU)**



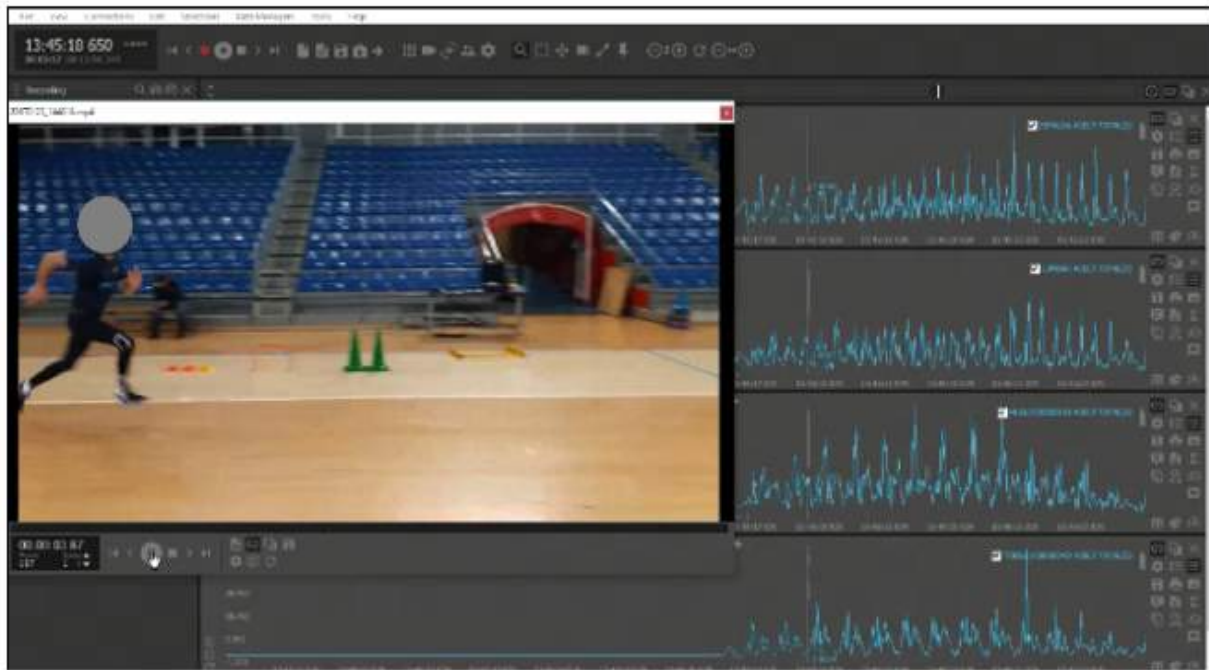
Adapted from WIMU devices (Realtrack Systems S.L.)

The variables analyzed in this test include step time, contact time, fly time, vertical stiffness, acceleration, and maximum force at each step. This analysis provides individual results for each limb. It also calculates the percentage of symmetry between limbs and the variation coefficient. The vertical stiffness of each player can also be assessed.

Similarly, another test that can be performed is the endurance test known as the Course Navette. This test lasts for 8 minutes and measures a player's submaximal aerobic endurance. In addition to monitoring heart rate during the test, inertial devices can be used for the steps test, which analyzes the impact behavior of both limbs, similar to the sprint example.

Following the advanced hurdle jump analysis presented earlier, the next figure displays G-forces measured during a linear sprint at maximum speed. The individual is equipped with inertial sensors placed in the same anatomical areas as in the jump test example.

**Figure 9: Behavior of acceleration measured using inertial devices placed in different anatomical areas during a linear sprint**

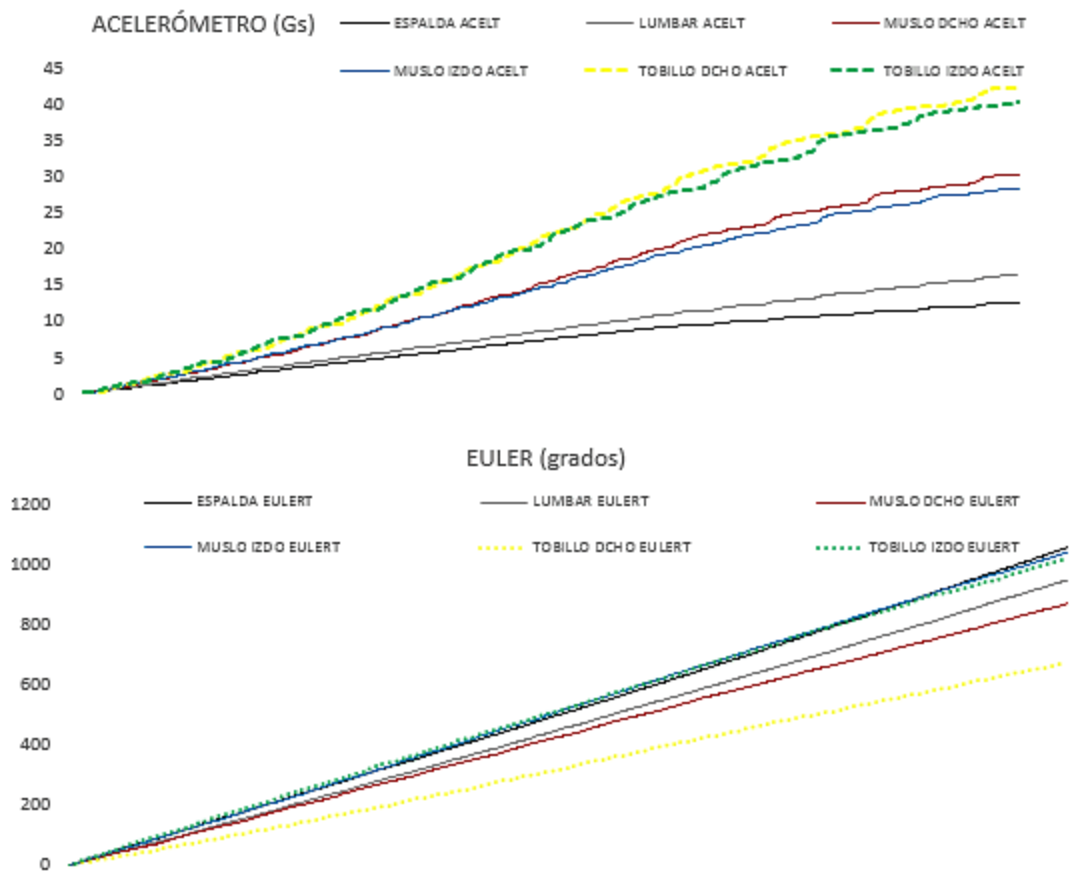


Source: Adapted from WIMU devices (Realtrack Systems S.L.)

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The following figure presents the analysis of these data, comparing acceleration measured in Gs and degrees (Euler) during the run, showing the results in each of the analyzed anatomical zones. In this example, the difference in acceleration between both limbs is minimal or practically nonexistent.

**Figure 10: Comparison of acceleration and degrees (Euler) between different anatomical zones and limbs during the linear sprint measured with inertial devices**



ACCELEROMETRO (Gs)	BACKACCELT	LOWER BACK ACCELT	RIGHT THIGH ACCELT
	LEFT THIGH ACCELT	RIGHT ANKLE ACCELT	LEFT ANKLE ACCELT

	EULER (degrees)		
	BACKEULER	LOWER BACK EULER	RIGHT THIGH EULER
	LEFT THIGH EULER	RIGHT ANKLE EULER	LEFT ANKLE EULER

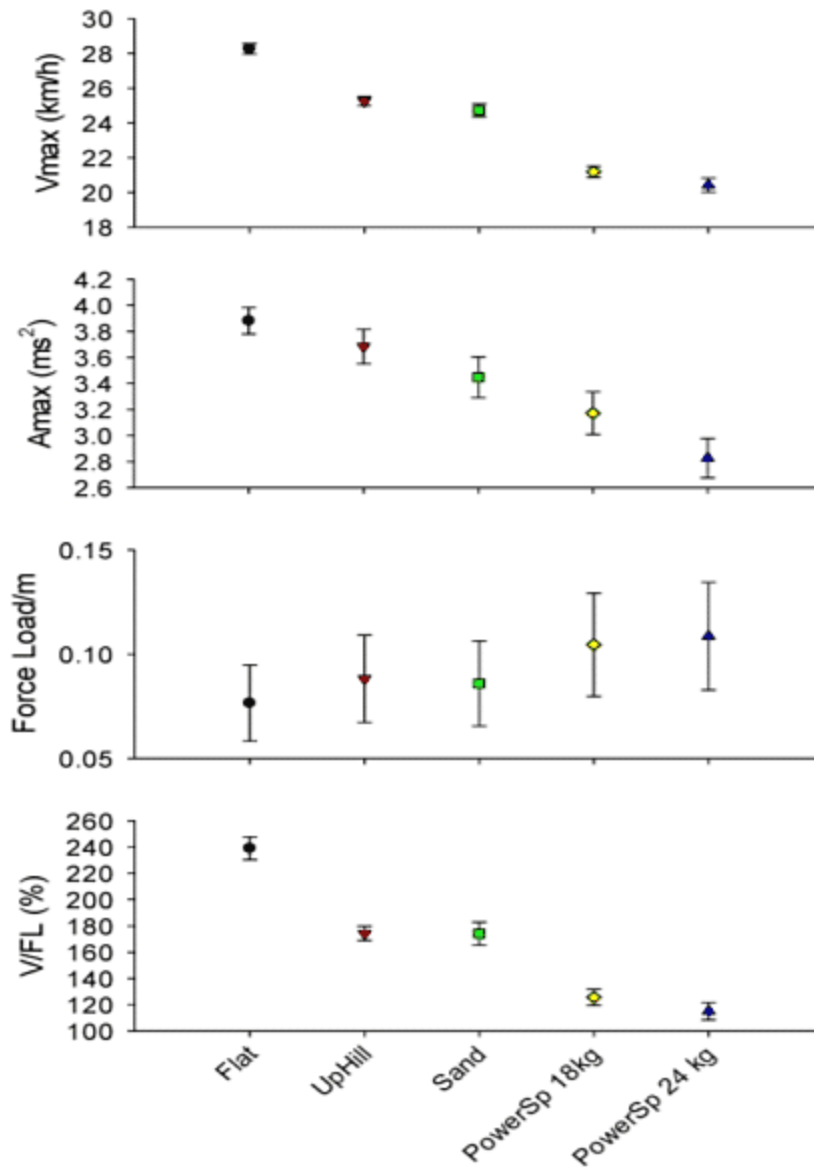
Source: Original work

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However, in this case, there is a noticeable difference in the degrees between both ankles. This difference is most likely due to a dorsiflexion deficit in one of them. Gómez-Carmona et al. (2020) validated the use of these devices for this type of measurement.

Meanwhile, Buchheit and Simpson (2017) conducted a study on a 15-meter sprint under different conditions (flat surface, a surface with a 4% incline uphill, a surface with sand, and using a machine offering resistance of 18 and 24 kg to simulate running). The authors sought to identify the variable with the greatest influence on exercise performance across each surface and the resistance machine. For example, both maximum speed and maximum acceleration were reached in the 15-meter sprint on a flat surface. However, the greatest force production was observed in the last of the proposed conditions (resistance machine with two different loads). This information helps tailor the design of training programs to achieve desired physical conditioning goals.

**Figure 11: Analysis of the 15-meter sprint under different conditions and with a resistance machine**

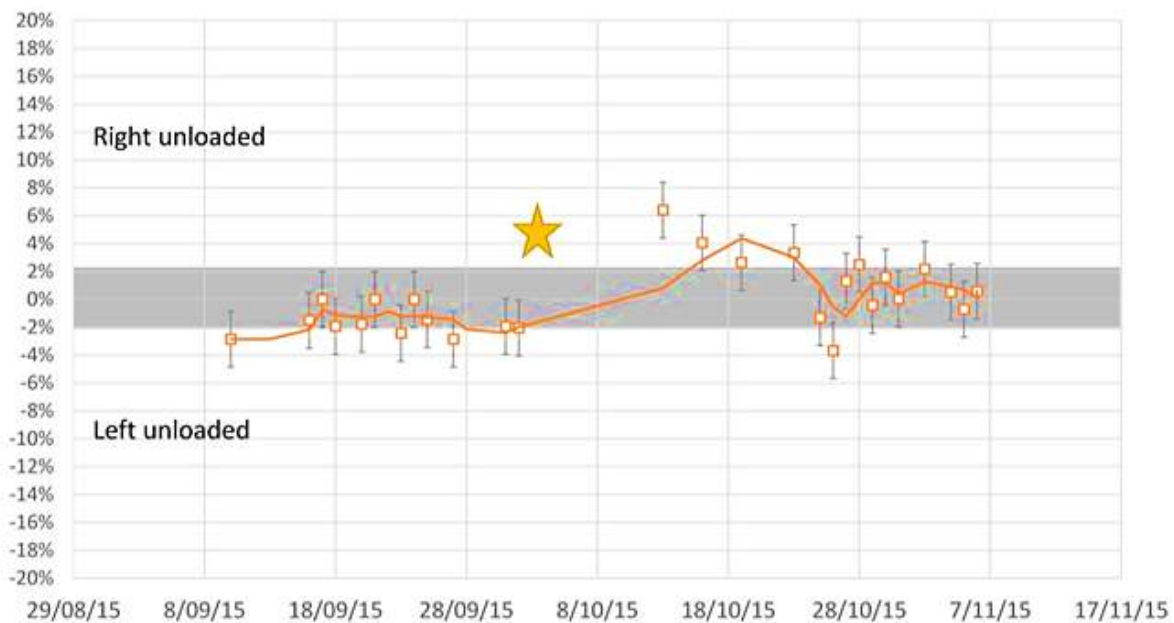


Source: Buchheit y Simpson, 2017, <https://goo.su/RSGrfJ>

Another practical application of these devices is their use in the rehabilitation process after an injury, such as an ankle injury. By analyzing a task or training session of a player who has suffered an injury, it is possible to understand the force or acceleration applied with each limb. In this way, training data before the injury can be

compared with current data during the rehabilitation process. The following figure shows how the player evaluated carried a similar load on both ankles before suffering an injury. However, right after sustaining an injury to the right ankle, a lower force production (reduced load-bearing) is observed compared to the uninjured ankle. Subsequently, during the return-to-play process, force production (load-bearing) stabilizes in both limbs.

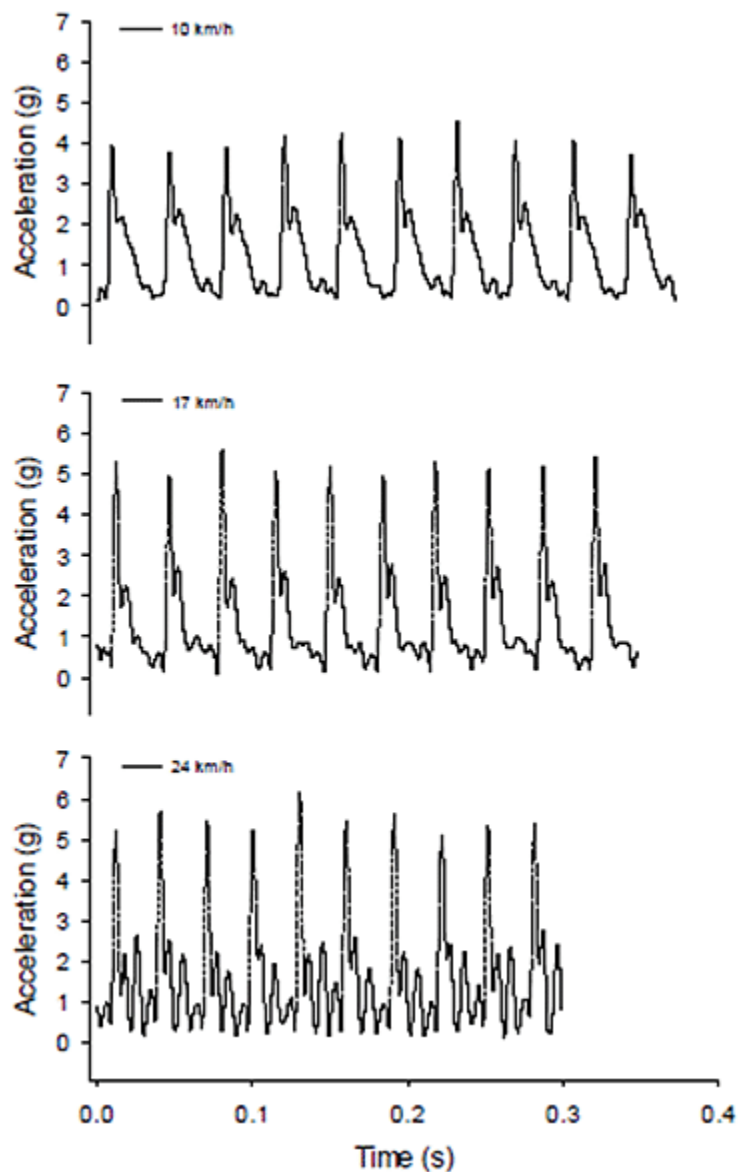
**Figure 12: Differences in the load-bearing of the lower limbs in a player with a right ankle injury, measured using an inertial system (IMU)**



Source: Buchheit y Simpson, 2017, <https://goo.su/RSGrfJ>

Another interesting study published by the same author (Buchheit et al., 2015) analyzed each step of a run performed at three different speed intensities using inertial systems. The next figure shows the acceleration data in G for each step at each measured speed.

**Figure 13: Analysis of acceleration in G for each step of a run performed at different intensities**



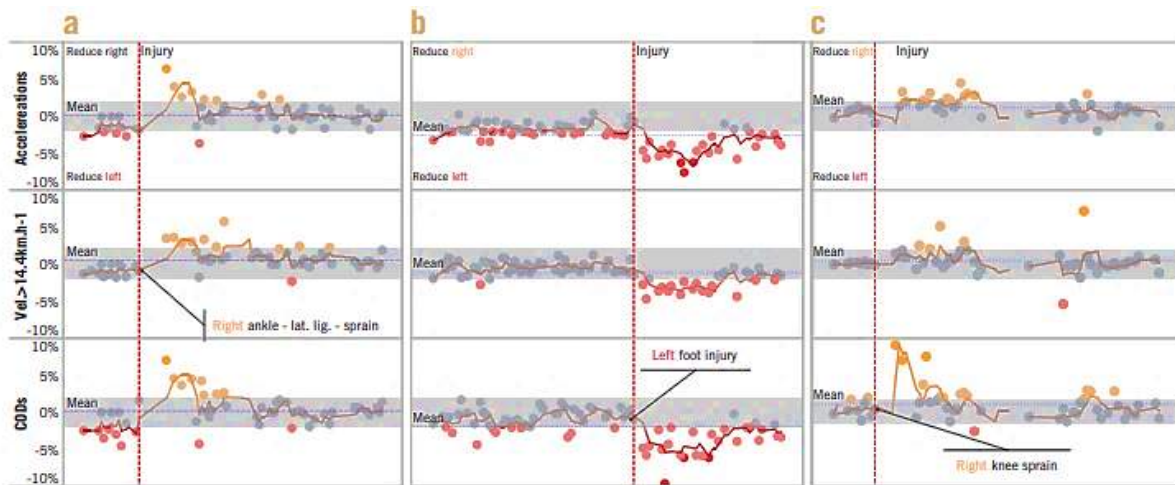
Source: Buchheit et al., 2015, <https://goo.su/r4W4Dn>

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The main conclusion of this study is that inertial systems allow for the assessment of contact time and vertical stiffness during running, as well as neuromuscular fatigue in running-based sports like indoor team sports. Therefore, this publication supports the use of this technology to detect potential asymmetries in running, as we previously presented.

In another publication, Lacombe et al. (2018) used these systems to monitor and evaluate the adaptations made before, during, and after a rehabilitation process for various types of injuries. To do this, they analyzed different variables, such as distance, high-intensity speed, and changes in direction. The following figure shows how the data indicate certain asymmetries between limbs in the various examples (red circles).

**Figure 14: Examples of symmetry evolution between limbs, measured using inertial devices across different variables before, during, and after an injury**

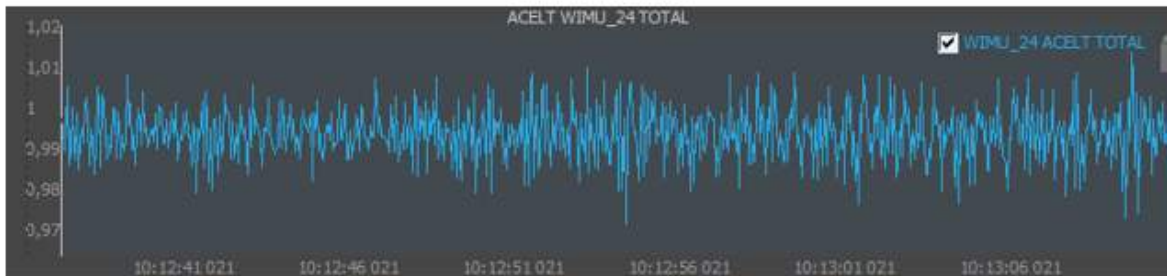


Source: Lacomme et al., 2018, <https://goo.su/NiPtDy>

In addition to the tests presented, inertial devices can estimate core stability. To assess this stability, different exercises involving the core were performed, calculating the coefficient of variation (CV) of the recorded acceleration signal. This produced a number that indirectly estimated the stability required in that exercise, where a higher result indicated a greater challenge for the core.

The following figure shows the coefficient of variation in a core stability exercise (front plank). CV = 0.64

**Figure 15: Acceleration signal used to calculate the coefficient of variation for a front plank**

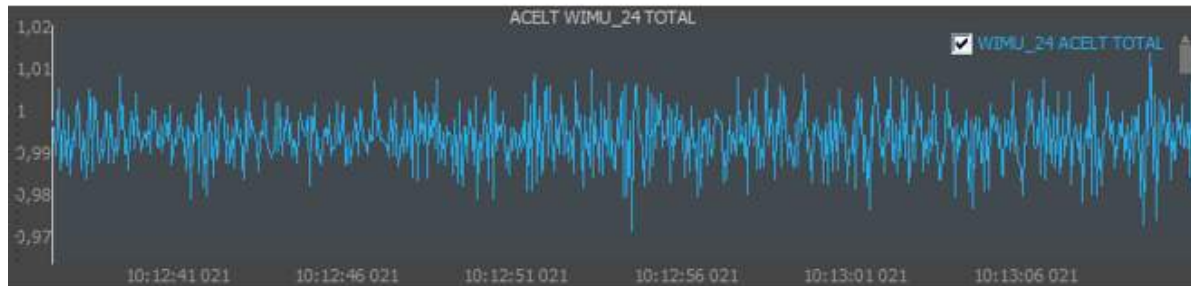


Source: Adapted from WIMU devices (Realtrack Systems S.L.)

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The following figure shows the CV for a side plank exercise, with a value of 0.91 (in this case, it could be compared to the contralateral side to observe potential asymmetries). This makes it possible to establish an objective progression measured through CV for core challenges. Again, the scientific literature supports the use of inertial systems to analyze trunk stability in this case (Bastida Castillo et al., 2018).

**Figure 16: Acceleration signal used to calculate the coefficient of variation for a side plank**



Source: Adapted from WIMU devices (Realtrack Systems S.L.)

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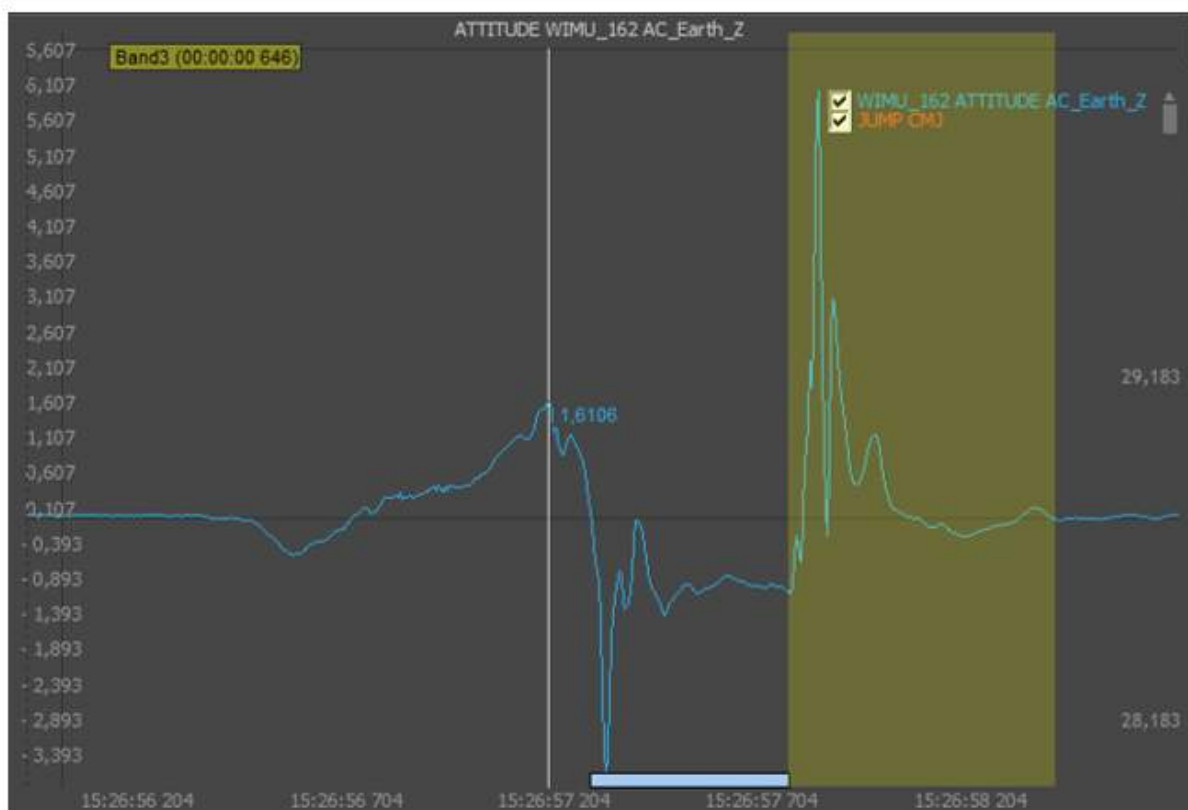
This same idea of using the CV calculation to measure trunk stability can also be used to estimate balance in different exercises and determine the level of challenge each exercise represents.

Additionally, these devices can measure the range of motion, such as performing a hip flexion while lying supine or an ankle dorsiflexion while standing. In this way, the degrees of movement of these joints can be evaluated. The hip flexion test has also been analyzed in the scientific literature using inertial systems (Muyor, 2017).

The next figure shows a test measuring the dynamic stability of landing on one leg in a jump (CMJ), performed with a takeoff phase on both legs. To obtain dynamic stability, the time to stabilization is calculated immediately after landing, first with one leg and then with the other (yellow shaded area in the figure). This test helps detect

potential deficits between both limbs in their ability to stabilize after performing a countermovement jump. Additionally, it allows for monitoring and evaluating the rehabilitation process after an injury. In this case, unlike the other tests presented, it is important to note that this one is not scientifically validated.

**Figure 17: Dynamic landing stability (time to stabilization) after landing on one leg in a bipodal CMJ jump**



Source: Adapted from WIMU devices (Realtrack Systems S.L.)

IMU devices also allow measurement of the following elements:

- The number of direction-change actions (Avilés et al., 2023), distinguishing between movement axes and monitoring their evolution in other sessions, while comparing results based on the type of session analyzed (Figure 18);
- The force produced in a squat performed on a Smith machine with different loads, differentiating between the concentric and eccentric phases of the movement (Muyor et al., 2018);
- A curvilinear test performed on the basketball three-point line (Baena-Raya et al., 2023).
- The mechanical load of a player running on a treadmill at different intensities (Figure 21).

Figure 18 shows the total and high-intensity direction changes made during a tactical training session by each player who participated. These data allow us to compare the results based on laterality (right and left) and the angles at which they occur. It is also useful to apply this monitoring during the rehabilitation phase of injuries.

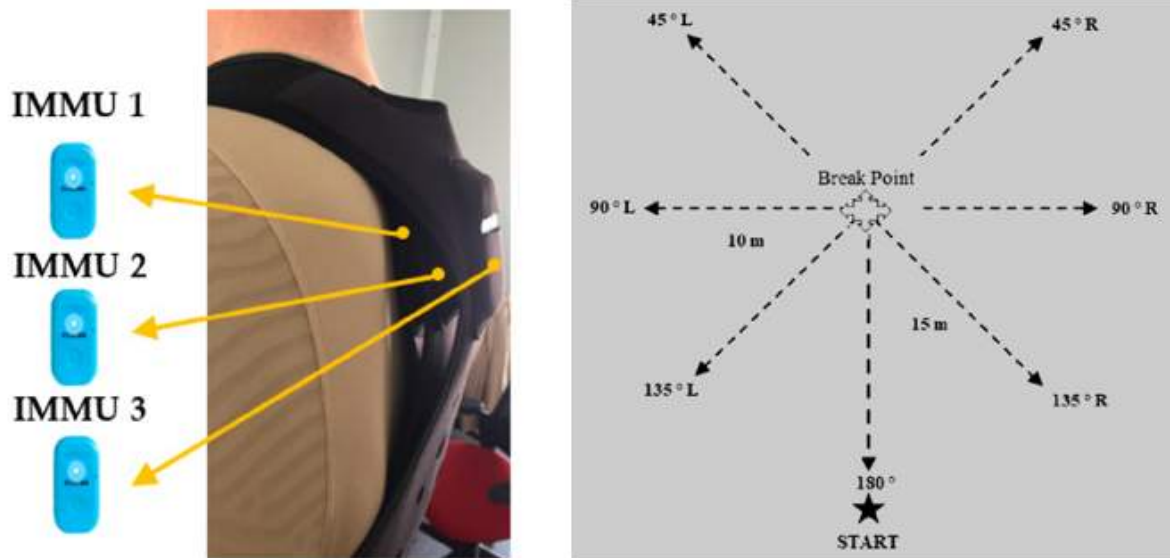
**Figure 18: Total and high-intensity direction changes (top) for each player**



Source: Adapted from WIMU devices (Realtrack Systems S.L.)

Regarding the previous data, scientific research also confirms their validity and reproducibility (Avilés et al., 2023). The results from this research demonstrate excellent reproducibility, precision, and validity of the inertial system used to detect changes in direction and inertia shifts. In summary, the new algorithm based on inertia changes provides reproducible, precise, and valid information for detecting direction changes in a standardized test with varying angles and speeds.

Figure 19: Location of inertial systems in the vest (left); test circuit (right)



Source: Avilés et al., 2023, <https://goo.su/xon16GJ>

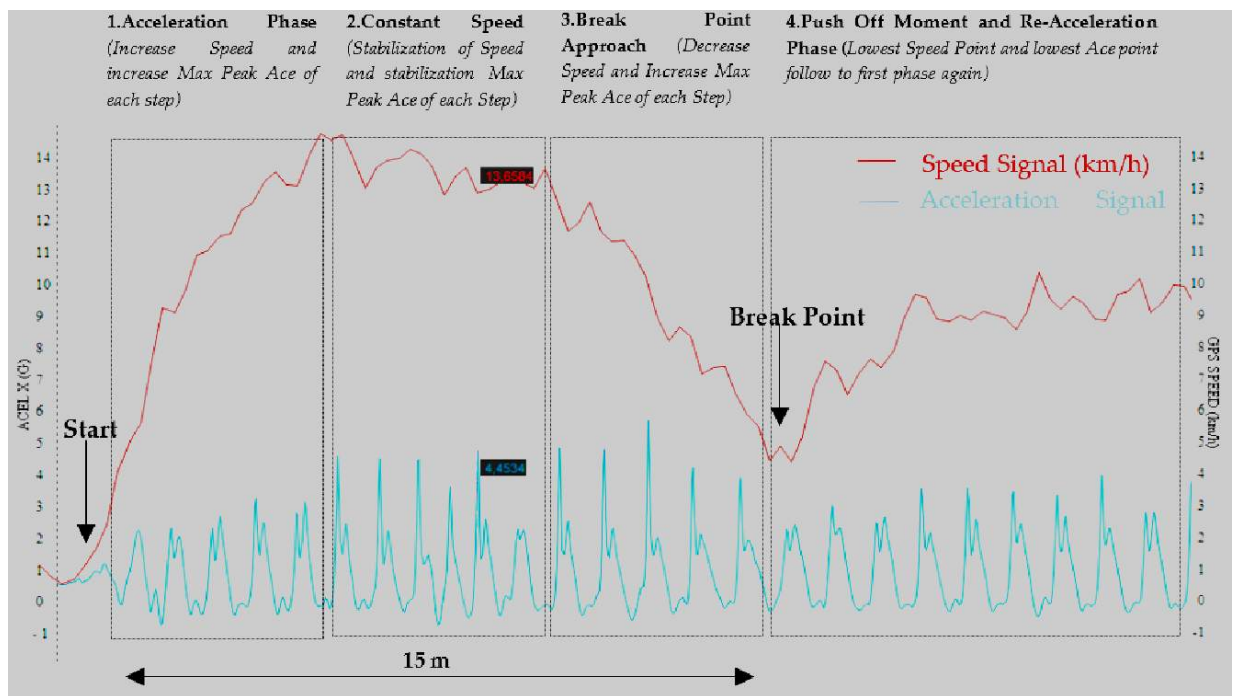
Figures 19 and 20 present the location of the devices on the subject's body and the circuit used to evaluate direction changes, as well as the acceleration channel of the X-axis (blue line) and speed (red line) during a 45° direction change at 13 km/h. The different biomechanical phases of the direction change can also be observed (Avilés et al., 2023).

IMU devices are capable of measuring the following elements:

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- The mechanical load experienced by a player running on a treadmill at various intensities
  - Curvilinear test conducted along the three-point line in basketball
  - Blood lactate levels
  - The number of direction changes performed

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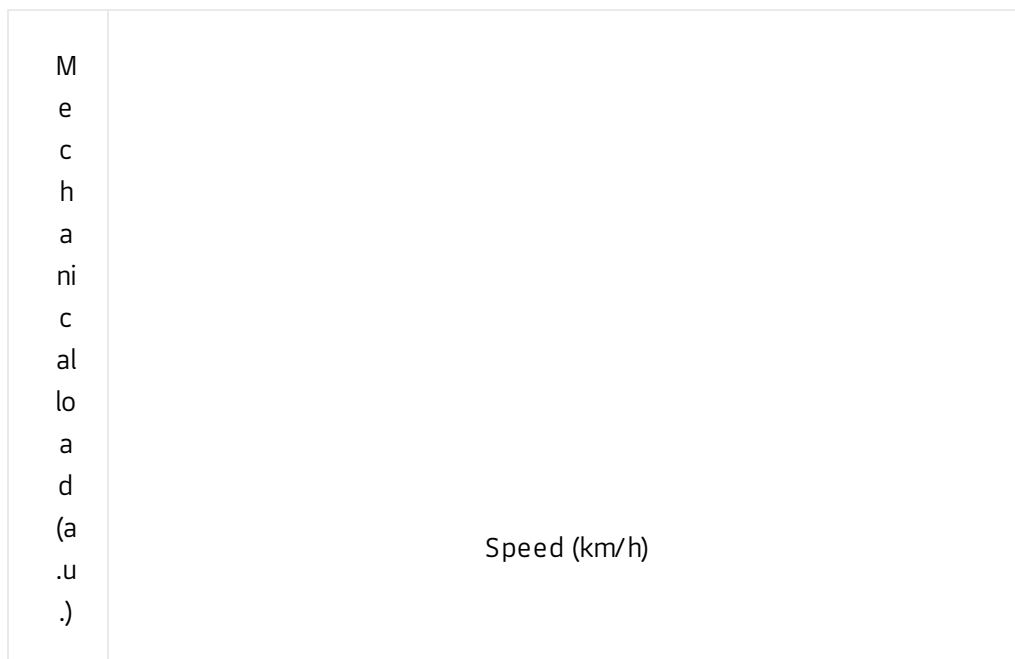
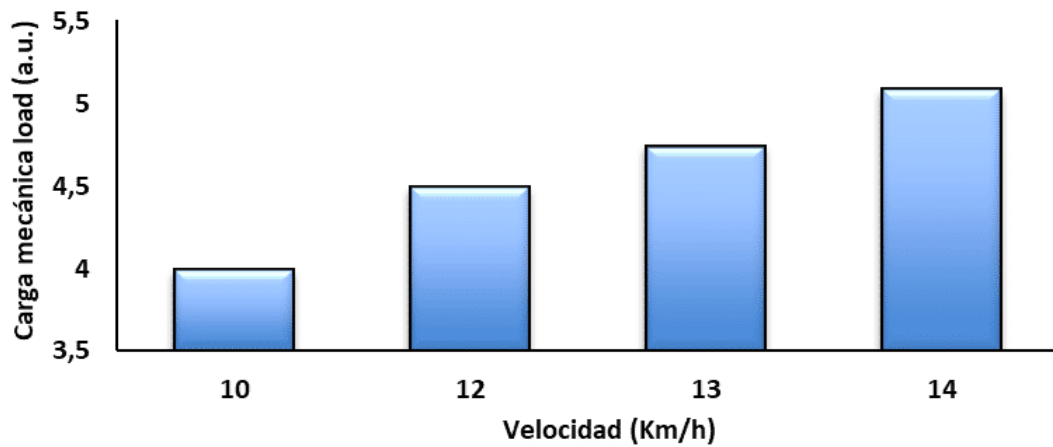
**Figure 20: X-axis acceleration (blue line) and speed (red line) during a 45° direction change at 13 km/h. Different biomechanical phases during a direction change**



Source: Avilés et al., 2023, <https://goo.su/xon16GJ>

As previously mentioned, inertial sensors can also measure the mechanical load of each running step, identifying differences between both legs. Additionally, a mechanical load can be quantified through the "player load" variable during running at different speeds, either on a track or treadmill (see Figure 21). It's also possible to measure the contribution of each axis in this or other types of movements. These aspects are especially useful during the injury rehabilitation process.

**Figure 21: Mechanical load while running on a treadmill at different intensities**

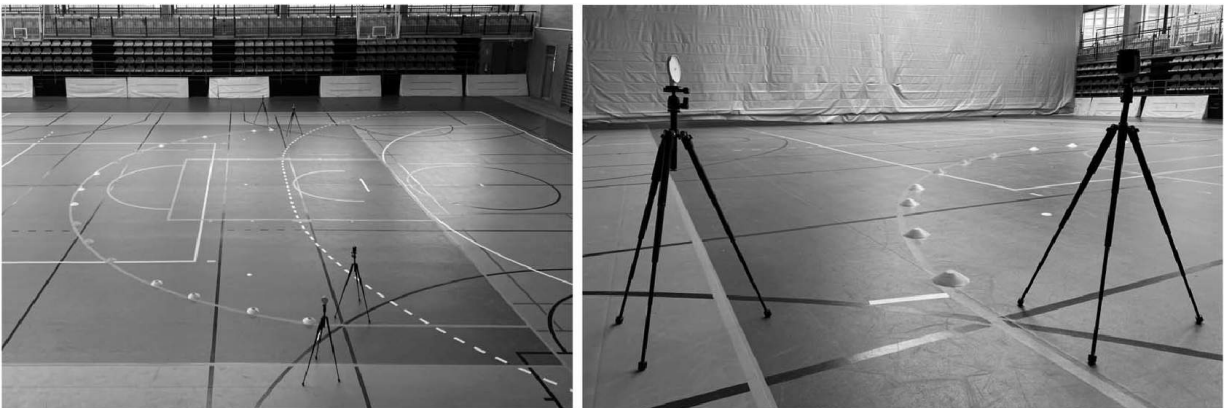


Source: Adapted from WIMU devices (Realtrack Systems S.L.)

Inertial systems can also be used to perform the curvilinear test on the basketball three-point line (see Figure 21). This test meets the demands of some indoor team sports by providing data such as maximum and average acceleration, speed, and centripetal force.

Scientific studies have demonstrated that the curvilinear sprint test is reliable for assessing physical performance in indoor team sports like basketball (Baena-Raya et al., 2023). The test reveals different kinetic and kinematic characteristics compared to the linear sprint test, emphasizing its importance for a more accurate evaluation of conditional structure.

**Figure 22: Schematic diagram of the curved sprint test along the basketball three-point line**



Source: Baena-Raya et al., 2023, <https://goo.su/U8zHtY>

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This set of tests, along with others conducted using these or similar systems, can be used to assess, monitor, and evaluate the training process and the state of conditional structure at any point during the season or throughout a player's career.

The use of microtechnology in high-level indoor team sports, including electronic performance tracking systems (EPTS) such as inertial systems, local positioning systems, and optical systems, has revolutionized performance monitoring. These systems enable the tracking of numerous parameters, primarily related to external load, but also to internal load, sustained by players during training sessions or competitions.

However, as stated at the beginning of this module, despite these technological advances, assessing some elements of load—especially internal load—remains challenging, particularly in areas beyond the conditional and bioenergetic structures (e.g., cognitive and emotional-volitional structures). To address this, we recommend complementing the tests discussed in this module, along with the monitoring tools outlined in previous modules, with two subjective questionnaires described below.

The first is the **Rating of Perceived Exertion** (RPE) questionnaire (Borg, 1982; Manzi et al., 2010), which helps quantify each player's perceived load during training sessions and matches, as illustrated in the following figure. This tool has been widely validated and frequently used in sports science literature, particularly in team sports.

**Figure 23: Adapted Borg Scale for Rating of Perceived Exertion (RPE)**

Cancel

Save answers

### Rating of Perceived Exertion (RPE)

What level of EFFORT did your last exercise or training session involve?



### Total Quality Recovery (TQR)

What is your level of RECOVERY in relation to your last exercise or training session?



Source: Original work

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The second is the **Wellness questionnaire** (Hooper et al., 1995), which assesses perceived well-being. This questionnaire evaluates sleep quality from the previous night, stress levels, overall fatigue, and muscle soreness before the next training session or competition.

**Figure 24: Wellness questionnaire using Hooper's scale**

## Sueño

Muy, muy bueno

Muy, muy malo



## Estrés

Muy, muy bajo

Muy, muy alto



## Fatiga

Muy, muy bajo

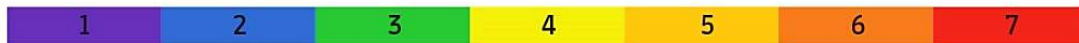
Muy, muy alto



## Dolor Muscular

Muy, muy bajo

Muy, muy alto



Sleep

Very, very good

Very, very bad

Stress

Very, very low

Very, very high

Fatigue

Very, very low

Very, very high

Muscle soreness

Very, very low

Very, very high

Source: Original work

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This information provides valuable insights into players' overall condition, helping to better understand their state of readiness.

The use of microtechnology, with electronic performance tracking systems (EPTS) includes...

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- Inertial systems and other complex systems
- Inertial systems, local positioning systems, and optical systems
- Three-dimensional and four-dimensional optical systems

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