ENHANCING ATHLETE PERFORMANCE: A COMPREHENSIVE ANALYSIS USING WEARABLE TECHNOLOGY

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Abstract. *This study explores the impact of a six-month training regimen on the performance of athletes with musculoskeletal impairments. Utilizing advanced wearable technology, including BTS G-WALK and G-STUDIO, we conducted a detailed analysis of the athletes' movement patterns and performance. The athletes demonstrated unwavering commitment throughout the training, adhering meticulously to prescribed procedures. The assessment revealed noteworthy improvements in speed and cadence, illustrated in Figure 6. Additionally, the paper discusses the integration of BTS SPORTLAB technologies in sports medicine, showcasing their role in individualized training plans, talent scouting, and clinical movement analysis. The findings highlight the importance of these technologies in optimizing athlete performance and minimizing injury risks. This study contributes to the evolving landscape of sports science by providing valuable insights into personalized training methodologies and the role of wearable devices in comprehensive performance evaluation.*

Keywords: *Athlete performance, wearable technology, musculoskeletal impairments, training regimen, movement analysis, gait parameters, BTS G-WALK, BTS G-STUDIO, sports medicine, individualized training, talent scouting, clinical movement analysis, injury risks, speed and cadence, sports science.*

Introduction. In the realm of international sports, competition among athletes with disabilities, particularly those with musculoskeletal injuries, has intensified. Consequently, a deeper understanding of their movement activity, physical fitness, and competition improvement rates, especially in endurance sports, is now essential. This necessitates a comprehensive analysis of objective data and an examination of various facets in their preparation.

While numerous studies have explored these issues— ranging from evaluations of overall performance and technical/tactical actions of disabled athletes to medical diagnosis and treatment of injuries— there has been a significant focus by researchers on specialized exercises to enhance coordination skills and biomechanical movement analysis. Special equipment has been developed for athlete classification, and laboratory conditions have been utilized to determine movement coordinates. Yet, there remains a gap in the research conducted on the development of specific exercises tailored to each individual's unique medical condition.

The routine analysis of temporo-spatial gait parameters is conducted by medical professionals to diagnose gait disorders, track disease progression, and evaluate the efficacy of various therapeutic strategies [1]. Researchers have employed both wearable and non-wearable systems for gait analysis, with wearable sensors presenting a unique advantage: the capability to analyze gait during everyday activities outside the confines of a laboratory [2]. While non-wearable systems tend to dominate controlled research environments, wearable sensors offer this unparalleled advantage, enabling the analysis of gait in real-world scenarios [2].

In the realm of gait analysis, inertial sensors, comprising accelerometers, gyroscopes, and occasionally magnetometers, are predominantly employed [2]. An accelerometer, a type of wearable inertial sensor, measures acceleration along a sensitive axis using Newton's motion laws. Conversely, gyroscopes function as angular velocity sensors, often incorporating principles from magnetometer technology, including magneto-resistive effects [3,7,12].

Lens-based motion capture technologies fall into two main categories: non-wearable systems, such as stereo photogrammetric and optoelectronic systems like VICON, Opti track, and BTS SMART-D, and wearable systems, exemplified by devices like the BTS G-WALK [4].

This research aims to monitor and evaluate the movement performance of disabled athletes with musculoskeletal impairments, utilizing both physical and technological methodologies.

A hardware and software complex for the functional analysis of the kinematic posture of paralypians. In this research, 35 athletes with disabilities participated. Preliminary biological parameters and the results of these athletes were analyzed. Based on the initial assessments, a training method was selected for each athlete, who then continued their practice. Following a six-month period, a subsequent monitoring session was conducted. Intriguingly, out of the 35 athletes, only one displayed a discernible change, as illustrated in Figures 4 and 5. Further evaluation indicated that the training provided did not effectively induce improvements. Consequently, athletes were provided with equipment tailored to their individual needs.

BTS SPORTLAB, with its integrated motion capture technology, provides sports medicine professionals with a crucial tool for acquiring comprehensive and objective data. This data facilitates functional analyses of athletes, allowing for the assessment of musculoskeletal conditions, movement strategies, and overall sports performance.

With its advanced capabilities, BTS SPORTLAB provides a reliable and precise method for monitoring athletes, thereby supporting their training, rehabilitation, and performance enhancement endeavors.

Internationally, sports teams, clubs, and Olympic committees, proving invaluable for talent scouting, embrace BTS SPORTLAB. This technology allows organizations to pinpoint promising athletes using objective criteria. BTS SPORTLAB also contributes to refining training regimens to optimize performance and reduce injury risks. Furthermore, it plays a key role in maintaining athletes' peak physical conditions throughout training and competitions. The widespread reliance on BTS SPORTLAB underscores its paramount importance and efficacy in sports performance analysis and athlete management [5, 6].

Through the utilization of BTS SPORTLAB, medical professionals can craft individualized training plans for athletes. This is achieved by gaining an in-depth comprehension of each athlete's potential and physical state. Such an approach reduces the risks of overtraining and ensures peak performance. BTS SPORTLAB facilitates a unified functional evaluation, focusing on four essential aspects: posture, movement, muscle activity, and strength. Assessing these dimensions provides a comprehensive perspective on an athlete's abilities, allowing training regimens to be tailored appropriately. This holistic approach not only enhances performance but also minimizes potential setbacks [5, 6].

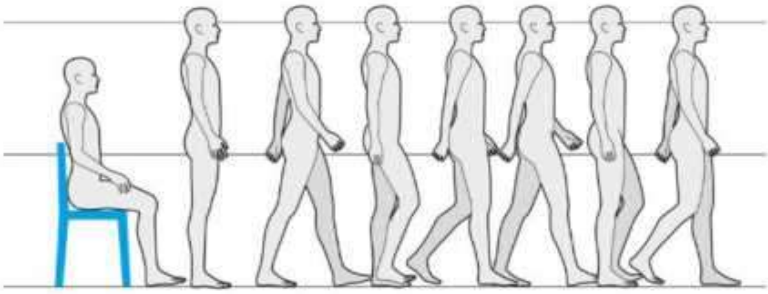

Figure 1. View of Timed Up and Go (TUG) trial execution, a commonly used mobility assessment, depicting the timed sequence of standing up from a chair, walking a short distance, turning, walking back, and sitting down.

In this study, the 'movement' factor of functional assessment was examined using the BTS G-STUDIO hardware and software, complemented by G-WALK, a wearable system designed for functional movement analysis. It's crucial to note that BTS G-STUDIO is an integral component of the comprehensive BTS SPORTLAB system. The combined use of these advanced technologies facilitated a thorough exploration and evaluation of the athletes' movement patterns and performance.

G-WALK excels at swiftly providing pivotal data essential for clinical movement analysis. In a matter of seconds, this cutting-edge wearable can conduct six straightforward tests, immediately comparing the outcomes with recognized standard ranges. The system's integrated protocols enable a meticulous evaluation of critical clinical trials, including:

Timed Up and Go

6 Minutes Walking Test

Walk+

Turn Test

Run

Jumps

Together, these tests cover a diverse spectrum of movements and tasks. This comprehensive assessment provides healthcare experts with invaluable insights into a patient's functional prowess and overall performance.

Crafted with four inertial platforms and cutting-edge GPS technology seamlessly integrated within a compact space of mere square centimeters, G-WALK ensures precision in its tracking. This intricate design enhances the accuracy of the assessment and notably reduces any margin for error. The device's expansive internal memory guarantees an impressive 8-hour continuous operation autonomy. Paired with its unrestricted range of motion, G-WALK allows unhindered movement during the data acquisition phase, as illustrated in [Table 1]. This fusion of features results in dependable and exhaustive monitoring of various activities, free from significant limitations.

G-WALK is a state-of-the-art wearable device seamlessly integrated onto a specialized belt, providing patients with unhindered freedom to walk, run, and jump throughout the assessment process. Embedded within the device is a sensor that wirelessly relays all data to a computer via Bluetooth. Upon completing each analysis, the system auto-generates a comprehensive report, detailing every parameter recorded during the test. These parameters, the result of 5 years of rigorous research, have received validation from internationally acclaimed clinical centers. The unwavering reliability and pinpoint accuracy of these parameters elevate G-WALK's clinical utility, making it an invaluable tool for patient assessment and monitoring.

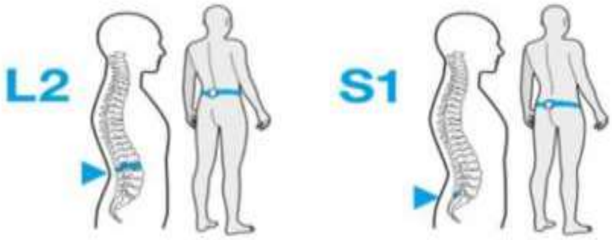

Figure 2. A view of the installation of the BTS G-WALK device on the lower back of the human body.

Results and discussion. The athlete's biological parameters, including [list specific parameters such as age, height, etc.], are detailed below:

Age: 26 years
Height: 168 cm
Weight: 48 kg
Gender: Male
Condition: Absence of the wrist section of the left hand due to an external incident

These parameters provide a comprehensive overview of the athlete's age, physique, and the specific disability affecting his left hand.

Table 1. Structure of bts g-walk device

Dimensions	70x40x18mm
Weight	37gr
Inertial Platforms	4 - Sensor Fusion technology
Inertial platform components	Triaxial Accelerometer 16bit/axes with multiple sensitivity: (±2, ±4, ±8, ±16 g) Triaxial Gyroscope 16bit/axes with multiple sensitivity: (±250, ±500, ±1000, ±2000 °/s) Triaxial Magnetometer, 13bit: (±1200 uT)
Battery	rechargeable via USB, 8 hours of autonomy
Connectivity	Bluetooth® 3.0, class 1, range up to 60 m LOS
Frequency	Accelerometer: from 4 to 1000 Hz Gyroscope: from 4 to 8000 Hz Magnetometer: up to 100 Hz GPS Receiver: up to 10 Hz Sensor Fusion: 200 Hz
Working	Real-time/batch
Memory	Internal Flash form 256MB (in Sensor Fusion mode up to 8h of continuous data recording)
Status LED	ON-OFF/charge

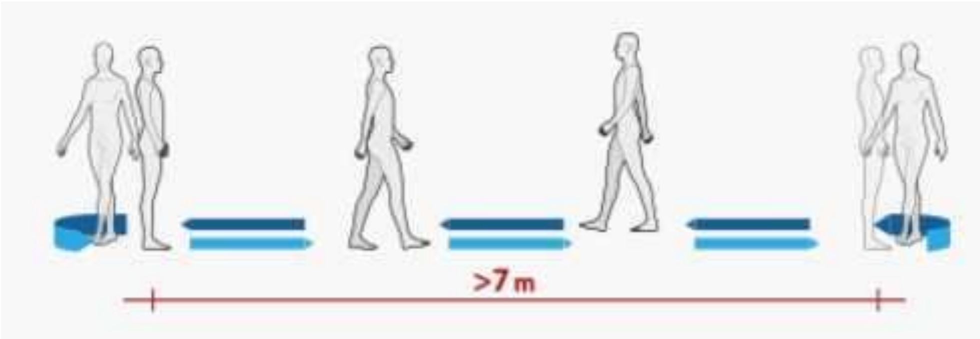

Figure 3. The process of implementation of preliminary results.

To capture the athlete's initial performance metrics, we utilized the 'Walk+' exercise. For this assessment, the device was strategically positioned on the S1 region of the athlete's physique. The athlete was then instructed to traverse a seven-meter distance, moving back and forth. The primary objective of this exercise was to meticulously evaluate the athlete's walking pattern and derive insights into various gait parameters. For a visual depiction of this exercise, please refer to Figure 3.

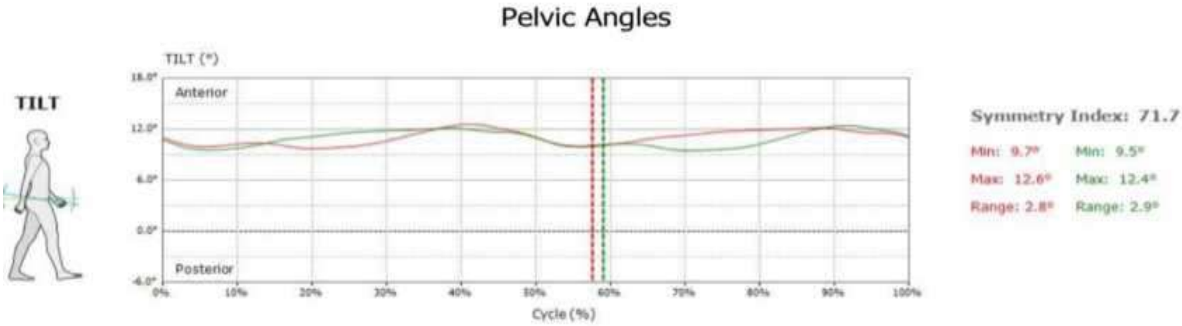

Figure 4. Preliminary TILT parameters of the Paralympic athlete.

Walk Analysis Report

Spatio-Temporal parameters	Value (Mean ± Std Dev)		Normal Value (Mean ± Std Dev)	Units
Analysis duration	15.7			s
Cadence	119.60 ± 3.07		118.80 ± 7.80	steps/min
Speed	1.62 ± 0.59		1.23 ± 0.11	m/s
Spatio-Temporal parameters	**Left Value (Mean ± Std Dev)**	**Right Value (Mean ± Std Dev)**	**Normal Value (Mean ± Std Dev)**	**Units**
Gait cycle duration	1.00 ± 0.01	1.00 ± 0.02	1.12 ± 0.15	s
Stride length	1.54 ± 0.42	1.68 ± 0.68	1.23 ± 0.07	m
% Stride length	91.63 ± 25.20	99.91 ± 40.32	84.70 ± 6.10	% height
Step length	47.94 ± 14.96	52.06 ± 25.39	50.00 ± 0.70	% str length
Stance phase	57.08 ± 0.53	58.50 ± 1.73	61.20 ± 2.70	% cycle
Swing phase	42.92 ± 0.53	41.50 ± 1.73	38.85 ± 2.75	% cycle
First double support phase	8.73 ± 1.53	7.49 ± 0.56	11.45 ± 2.65	% cycle
Single support phase	41.05 ± 1.44	42.40 ± 0.49	38.85 ± 2.75	% cycle
Elaborated steps	8	9		

Figure 5. Preliminary kinematic parameters of the Paralympic athlete.

Throughout the six-month training regimen, the athlete demonstrated unwavering commitment by meticulously adhering to the prescribed training procedures. Their activities were closely supervised, resulting in the following noteworthy observations:

Speed and Cadence: Recorded improvements included an increase in the athlete's speed and the number of steps taken per minute, as illustrated in Figure 6.

As discerned from the graph in Figure 6, the initial observations showed the athlete moving at a speed of 1.65 m/s, taking 120 steps per minute. Post-training, however, there was a discernible shift: the speed reduced to 1.45 m/s, while the cadence rose to 122 steps/min.

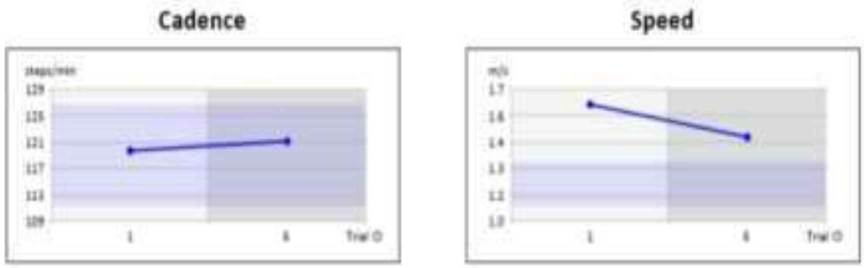

Figure 6. A graph of the athlete's speed and steps per minute. Here are the 1st preliminary results; 6. Results obtained after six months.

This alteration in speed and cadence points to significant adaptations in the athlete's movement dynamics and internal energy distribution. It seems that by honing the directionality of energy expenditure tailored to specific tasks, the athlete has become more kinetically efficient. This is evidenced by a slower speed paired with a quicker cadence, suggesting an enhanced energy utilization and a more refined movement strategy. Such developments not only highlight the athlete's evolving proficiency but also underscore a heightened ability to optimize energy transference during physical exertions.

Stance phase and Swing phase (Figure 7):

From the insights gleaned from Figure 7, there's a discernible evolution in the athlete's leg movements, showcasing greater stabilization when juxtaposed against the initial results. This progression underscores the athlete's augmented capability to exert precise control, ensuring consistent stability during leg movements throughout the training duration.

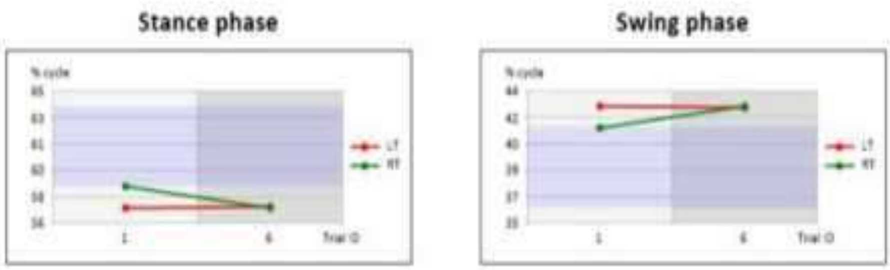

Figure 7. Stance phase and Swing phase. Here are the 1- preliminary results; 6 - results obtained after six months.

Achieving such stabilization in leg movements is not only commendable but is also indicative of improved balance, heightened coordination, and refined command over the lower limbs. Such advancements suggest that the athlete has honed their proprioceptive skills and muscular control. The resultant controlled and stabilized leg movements are pivotal for amplifying performance, mitigating injury risks, and fostering enhanced movement efficiency.

General symmetry and Pelvic symmetries (Figure 8):

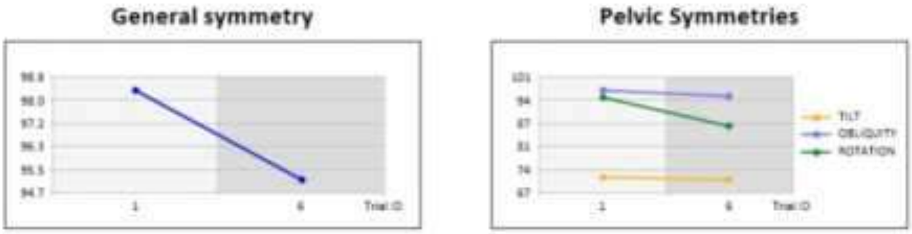

Figure 8. General symmetry and Pelvic symmetries. Here are the 1- preliminary results; 6 - results obtained after six months.

Based on the data presented in Figure 8, we can observe the athlete's general and pelvic symmetries. A comparison between the preliminary results (1) and the findings after the six-month period (6) reveals a notable decline in both general and pelvic symmetries during the initial assessment.

This reduced symmetry can largely be attributed to the absence of the athlete's left wrist due to an external incident. To counterbalance this deficit and strive for symmetry, the athlete's body might have instinctively shifted its reliance to the left hand—which, unfortunately, is no longer there. This irregular distribution of support could have necessitated the body to draw on extra energy.

Throughout the training regimen, measures were implemented to reallocate the energy, which was previously channeled to the left hand, to alternate support points in the body. This deliberate recalibration sought to streamline energy dispersal, attenuating the influence of the missing left hand. The outcome? The athlete manifested enhanced symmetry and optimized energy usage, culminating in a more efficient movement mechanism.

Such findings underscore the athlete's remarkable bodily adaptability and vouch for the efficacy of the training approach—aimed at harnessing energy efficiently and upholding symmetry, even in the face of a physical setback like the absent left hand.

Conclusion. This study underscores the remarkable adaptability of athletes with physical disabilities, illustrating their ability to evolve and achieve body symmetry in cyclical sports. The meticulous monitoring and assessment of their training and activities have yielded significant insights, highlighting the efficacy of the methods employed. By diving deep into specific datasets, the tangible impact of their training regimens can be discerned.

The hardware and software tools leveraged, especially the G-Walk device, manifest immense potential. They open up avenues not just within cyclical sports, but across a broader spectrum of athletic disciplines, empowering athletes with disabilities. Crucially, these tools facilitate the customization of training strategies, tailoring them to the unique needs and conditions of each individual athlete.

Throughout the research, the G-Walk device was instrumental in offering a granular analysis of the athlete's physical and biological states. The promise shown by analyzing the kinematic conditions of athletes with disabilities through G-Walk is undeniable.

Looking ahead, delving further into this technology holds the key to groundbreaking advancements. It can pave the way for refined training approaches and performance augmentation for athletes with disabilities, spanning a diverse array of sport.

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