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Gait analysis of male professional boxers

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Abstract

Introduction: Gait plays a crucial role in both daily life and sports performance. This study analyzes professional boxers' gait, as it is essential to understand its influence on performance and injury risk. However, there is a need to comprehend the effects of boxing training on gait and the occurrence of asymmetries between limbs. Research Question: Does the gait of professional boxers exhibit significant differences between limbs, and what are the potential implications of this asymmetry? Materials and Methods: The study involved 36 professional boxers, and the Gaitway 3D Pressure treadmill was used to collect data. The analysis was performed using statistical tests with a pre-determined level of significance. Results: Significant differences were found between limbs in gait phase parameters and ground reaction forces. A longer swing phase of the right leg was observed, potentially affecting the reduction of single-limb support and right-leg propulsion. Additionally, higher ground reaction forces were noted on the left side. Conclusions: This analysis of gait in professional boxers provides valuable insights into the asymmetry between limbs, which may impact performance and injury risk. It also shows the correct characteristics of selected gait parameters. These findings are relevant for tailoring training programs, reducing injuries, and enhancing overall physical conditioning of athletes. Further-more, they can be applied in both sports and daily life for injury prevention and rehabilitation, where maintaining balance and stability are crucial in avoiding injuries and improving the quality of life.

Keywords

gait, proffessional boxers, walking, asymmetry, ground reaction forces, training programs.

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Article

Gait analysis of male professional boxers

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Abstract: Introduction: Gait plays a crucial role in both daily life and sports performance. This study analyzes professional boxers' gait, as it is essential to understand its influence on performance and injury risk. However, there is a need to comprehend the effects of boxing training on gait and the occurrence of asymmetries between limbs. Research Question: Does the gait of professional boxers exhibit significant differences between limbs, and what are the potential implications of this asymmetry? Materials and Methods: The study involved 36 professional boxers, and the Gaitway 3D Pressure treadmill was used to collect data. The analysis was performed using statistical tests with a pre-determined level of significance. Results: Significant differences were found between limbs in gait phase parameters and ground reaction forces. A longer swing phase of the right leg was observed, potentially affecting the reduction of single-limb support and right-leg propulsion. Additionally, higher ground reaction forces were noted on the left side. Conclusions: This analysis of gait in professional boxers provides valuable insights into the asymmetry between limbs, which may impact performance and injury risk. It also shows the correct characteristics of selected gait parameters. These findings are relevant for tailoring training programs, reducing injuries, and enhancing overall physical conditioning of athletes. Further-more, they can be applied in both sports and daily life for injury prevention and rehabilitation, where maintaining balance and stability are crucial in avoiding injuries and improving the quality of life.

Keywords: gait, professional boxers, walking, asymmetry, ground reaction forces, training programs.

1. Introduction

Gait is one of the most important individual characteristics of every human, illustrating their posture in motion. Gait analysis provides an opportunity to assess gait by identifying gait kinetics, gait kinematics, and musculoskeletal activity. Gait analyses used for gait assessment are applied in rehabilitation, clinical diagnostics, and also in sports [1].

Gait analysis helps determine its parameters and examine biomechanical actions occurring during walking. Therefore, it is a significant part of health diagnostics, both in rehabilitation and in sports. Gait analysis of professional basketball players revealed significant correlations between performance levels and players' gait parameters [2].

The key to success and victory in boxing lies not only in upper limb work and strength but also in lower limb function. Lower limb muscles in boxing are utilized not only to demonstrate functional skills but also to maintain balance. Antagonistic muscles play an important role – the quadriceps muscle generates scissor force on the tibia forward during normal walking compared to the femur, while the hamstring tendon opposes this force, allowing the quadriceps muscle to absorb it and provide dynamic stability in the knee joint. Weakening of the quadriceps muscle affects daily activities such as walking pace, balance maintenance, stair climbing, and rising from a seated position [3]. Improper gait caused by various pathologies or overloads combined with intensive training can be a cause of bone injuries in athletes [4].

Experimental studies conducted by Aoki et al. [5] demonstrate that physical fatigue can be detected based on gait. Furthermore, the authors' proposed approach is not limited to fatigue classification but can also be applied to other issues in which changes in gait accompany physical and psychological states, such as emotion detection and mood disorders, which can also impact human gait [5], making it highly relevant in sports, particularly for professional athletes.

Boxing is one of the most popular and oldest combat sports, in which two athletes, usually wearing protective gloves, exchange punches in a boxing ring for a specified time. Boxing has a golden history dating back thousands of years, with the earliest evidence of boxing found in ancient civilizations [6]. Combat sports, including boxing, are complex sports that require boxing skills and dynamism. These skills are executed in a combined or isolated manner depending on whether the athlete is on the offensive, defensive, or counterattacking. Utilizing boxing skills demands fundamental technical and tactical knowledge from athletes, which must be refined and developed through training methods that optimize skills, considering the athletes' individual characteristics [7]. Martial arts demand coordination, agility, and manual dexterity [8,9] as numerous systems and organs of the human body are involved during combat [10].

The level of athletic proficiency in qualified boxers is determined by a combination of various factors: physical, technical, theoretical, psychological, and others, each of which addresses specific challenges. Physical fitness contributes to the development of muscle strength, endurance, agility, accuracy of strikes, and improvement in body balance [11–13]. Scientific reports have shown that different combat techniques can help develop and enhance motor skills [14–16]. Boxing training, including traditional stretching, strength training, and endurance training, can be considered effective in improving flexibility, dynamic balance, walking speed, and overall quality of life [17].

Gait analysis allows for customizing the training cycle according to the athletes' individual needs, aiming to improve motor skills and prevent injuries. Despite the increasing popularity of combat sports and the numerous publications on subjects like boxers, there is still an insufficient amount of research concerning gait and balance analysis. The main objective of this study is to assess selected gait parameters in individuals who professionally practice boxing.

2. Materials and Methods

2.1. Participants

The study involved 36 male boxers aged 19–30 (n = 36, mean body mass: 77.03 ± 8.15 kg, mean body height: 176.1 ± 6.76 cm). The athletes participating in the study attended training sessions five times a week. All men who qualified for the study met the inclusion criteria, which were: possession of a license from the Polish Boxing Association, no injury in the 6 months preceding the study, no cardiovascular, metabolic or pulmonary problems, and no intense activity 48 hours before the measurements. In addition, a condition for the athletes' participation was used in combat operations orthodox stance, with the left upper and lower limb (hereinafter understood as the forward leg) moved forward, and the upper and lower right ones (hereinafter understood as the rear leg) withdrawn. The study was conducted with the consent of the Research Ethics Committee of the University of Warmia and Mazury in Olsztyn (decision no. 9/2018).

2.2. Instruments

Body mass was measured using the Tanita InnerScan®V model BC-545N (Tanita Corporation, Maenocho, Itabashiku, Tokyo, Japan), body height was measured using an elec-tronic Soehnle height meter (Soehnle, Gaildorfer Straße 6, 71522 Backnang, Germany). Gait parameters were collected using the Gaitway 3D Pressure treadmill (Noraxon USA, Scottsdale, AZ, USA), and the data were exported using the Mayo Research (MR3) soft-ware from the same company.

2.3. Procedures

Measurements for data analysis were taken in a specially prepared room where natural light was used, and the temperature was maintained at 22°C. Tests for habitual walking speed took place in a well-lit corridor, where the temperature was also 22°C. To avoid external influences, privacy was assured for each athlete. Participants were familiarized with the purpose and procedure of the study, and they were informed that they could withdraw from the study at any time. Each athlete signed an informed consent form in accordance with the Helsinki Declaration of the Association (2013). Participants were tested in the afternoon between 14:00 and 18:00. The tests were performed at least 3 hours after the last meal. Before proceeding with the measurements, each participant was asked to fill out a health status form and an informed consent questionnaire for the study. Using the Tanita InnerScan®V model BC-545N, body mass was measured, and height was measured using the Soehnle electronic height meter. Each athlete then performed a 10–15 minute warm-up, 5 minutes of jogging and 10 minutes of general warm-up (conditioning) and stretching (flexibility).

For treadmill adaptation, each participant was tasked with walking at their natural pace a distance of 20m, marked by a start and end marker, three times. Participants were instructed to stand with their toes just behind the starting line and to start walking on the command "Go." Walking speed was controlled by a stopwatch.

After the warm-up and treadmill adaptation, subjects were asked to walk naturally on the Gaitway 3D treadmill. The walking was conducted at a speed of 1.5 ± 0.01 m/s. All participants were asked to stand on the treadmill, with evenly distributed body weight. The subject's gaze was directed straight ahead with upper limbs along the body. Three analyses were recorded, and averages were calculated for three repetitions of selected gait parameters.

2.4. Statistical Analysis

Descriptive statistics (Mean, Minimum, Maximum, 1st Quartile, 3rd Quartile, Standard Deviation) were calculated for all variables. The Shapiro-Wilk test was used to determine the normality of the data. Some of the analyzed parameters had nonparametric data, hence the Wilcoxon matched-pairs signed-rank test was used for statistical analysis. The level of statistical significance was set at $p \leq 0.05$. Statistical analyses were performed using the Statistica program (StatSoft Polska, Kraków, Poland version 13.3).

3. Results

The results of the statistical analysis of parameters concerning Length of Gait Line, Single Support Line, and COPy presented in Table 1 did not show statistically significant differences for any of the examined parameters between the left and right sides. Only in the COPx parameter (center of pressure along the X axis and relative to the reference origin) were statistically significant differences observed, indicating that the center of pressure along the X axis is higher in the left leg than in the right one ($p = 0.000$).

Table 1. Statistical analysis of COP parameters (COP Parameters).

	Mean	Min	Max	Q1	Q3	SD	Z	p
Length of gait line left [mm]	241.70	164.76	281.81	234.55	254.31	25.84	1.415	0.157
Length of gait line right [mm]	238.85	139.71	279.01	237.61	251.96	29.07		
Single Support Line left [mm]	115.02	45.58	130.41	112.94	126.53	19.23	0.762	0.446
Single Support Line right [mm]	114.23	35.43	144.55	104.52	127.31	23.17		
Ant/Post Position [mm]	148.86	127.86	212.53	139.53	153.08	18.17	-	-
Lateral Symmetry [mm]	0.77	-5.73	9.59	-2.08	4.53	4.09	-	-
COPx LT [mm][a]	167.87	118.37	228.35	145.13	199.58	31.42	3.724	0.000*
COPx RT [mm][a]	21.49	0.00	116.02	0.00	29.78	30.66		
COPy LT [mm][a]	366.50	148.51	595.47	273.50	468.34	121.34	1.328	0.184
COPy RT [mm][a]	362.05	128.68	574.08	261.79	455.08	119.58		

LT: Left; RT: Right; Figures are expressed as total maximum force. COPx: center of pressure along the X (lateral) axis and relative to the reference origin. COPy: center of pressure along the Y (anterior-posterior) axis and relative to the reference origin.
Z: Wilcoxon test; *significance level $p \leq 0.05$.

Parameters related to gait phases in the examined boxers presented in Table 2 showed statistically significant differences in the Stance Phase ($p = 0.018$), Single Support Phase ($p = 0.018$), and Swing Phase ($p = 0.018$) between the left and right sides. The statistical analysis revealed that the participants in the study have significantly longer Swing Phase in the right leg compared to the left leg; consequently, the Single Support Phase and Stance Phase in the right leg are shorter than in the left leg. The remaining parameters, Load Response and Pre-swing, did not show statistically significant differences between the left and right legs.

Table 2. Statistical analysis of gait phase parameters (Gait Phase Parameters).

	Mean	Min	Max	Q1	Q3	SD	Z	*p*
Stance Phase left [%]	61.68	59.76	64.08	61.00	62.78	1.11	2.373	0.018*
Stance Phase right [%]	61.33	59.69	62.72	60.68	62.19	0.90		
Load Response left [%]	11.38	9.85	12.99	10.79	11.85	0.83	0.980	0.327
Load Response right [%]	11.63	9.64	14.19	10.87	12.79	1.24		
Single Support left [%]	38.67	37.26	40.32	37.80	39.32	0.90	2.373	0.018*
Single Support right [%]	38.32	35.93	40.24	37.22	39.01	1.11		
Pre-swing left [%]	11.63	9.64	14.20	10.87	12.80	1.25	0.980	0.327
Pre-swing right [%]	11.38	9.86	12.99	10.78	11.85	0.82		
Swing Phase left [%]	38.32	35.92	40.24	37.22	39.00	1.11	2.373	0.018*
Swing Phase right [%]	38.67	37.28	40.31	37.81	39.32	0.90		
Double Stance [%]	23.01	20.02	26.47	21.61	24.98	1.94	-	-

Z: Wilcoxon test, *significance level $p \leq 0.05$.

Spatial parameters of gait subjected to statistical analysis, presented in Table 3, including Foot Rotation and Step Length, did not show significant differences between the left and right sides.

Table 3. Statistical analysis of gait spatial parameters (Gait Spatial Parameters).

	Mean	Min	Max	Q1	Q3	SD	Z	*p*
Foot Rotation left [deg]	6.91	-5.22	16.82	3.31	10.97	6.02	0.501	0.616
Foot Rotation right [deg]	7.89	-6.45	21.25	3.83	12.68	6.40		
Step Length left [cm]	73.66	67.31	82.45	71.29	75.82	3.92	0.240	0.811
Step Length right [cm]	74.01	66.61	84.87	70.48	75.97	4.47		
Stride Length [cm]	147.67	133.91	165.03	141.93	151.51	7.99	-	-
Step Width [cm]	12.77	6.62	18.91	10.17	15.51	3.12	-	-
Velocity [km/h]	5.51	5.40	5.62	5.46	5.56	0.07	-	-

Z: Wilcoxon test; *significance level $p \leq 0.05$.

The step time of the left and right side during the analysis, whose results are presented in Table 4, did not show statistically significant differences.

Table 4. Statistical analysis of gait time parameters (Gait Time Parameters).

	Mean	Min	Max	Q1	Q3	SD	Z	*p*
Step Time left [ms]	482.06	439.37	535.92	464.09	490.50	24.49	0.631	0.528
Step Time right [ms]	482.99	444.02	536.55	465.84	497.46	24.29		
Stride Time [ms]	965.05	883.38	1072.47	923.86	991.08	48.11	-	-
Cadence [step/min]	124.66	111.93	135.92	121.11	129.90	6.09	-	-

Z: Wilcoxon test; *significance level $p \leq 0.05$.

Table 5 presents the Force Impact Analysis, and the ground reaction lateral force showed a statistically significant difference (p=0.000), indicating that the ground reaction lateral force is higher on the left side than on the right side. However, the other parameters, ground reaction vertical force and ground reaction anterior-posterior force, did not show statistically significant differences.

Table 5. Analysis of ground reaction forces (Force Impact Analysis).

	Mean	Min	Max	Q1	Q3	SD	Z	*p*
Fx LT [N][a]	240.93	133.55	441.27	172.37	257.08	89.85	3.636	0.000*
Fx RT [N][a]	165.50	81.92	396.19	114.82	188.02	73.94		
Fy LT [N][a]	295.66	219.04	415.18	258.72	351.62	54.25	0.806	0.420
Fy RT [N][a]	299.73	228.52	391.22	262.27	346.26	54.48		
Fz LT [N][a]	1141.65	702.97	1504.76	974.01	1318.59	233.74	0.893	0.372
Fz RT [N][a]	1155.44	717.90	1565.47	1043.86	1271.55	230.00		

LT: Left; RT: Right; Figures are expressed as total maximum force. FZ: ground reaction vertical force. FY: ground reaction anterior-posterior force. FX: ground reaction lateral force. Z: Wilcoxon test; *significance level $p \leq 0.05$.

4. Discussion

The aim of the study was to investigate the gait parameters of high-level boxing athletes. Acquiring new knowledge and fostering positive attitudes towards proper biomechanics of movement and possible gait re-education among boxers could help them in their life beyond professional sports (proper gait as a natural form of locomotion), optimizing training and competitive activities, and reducing susceptibility to injury. The literature indicates that observing an athlete's walking style and persistent practice for improvement, in case of gait deformities, will increase performance effectiveness and reduce the risk of injury [18, 19]. Gait diagnostics are used to identify the structural-functional profile of athletes in various disciplines, such as running, triple jump, swimming, golf, bowling, tennis, baseball, badminton, and cricket [20–23].

In this study, significant differences of selected COP parameters, gait phases, and ground reaction forces were observed in a comparison between the right and left foot. In the COPx parameter, an asymmetry was noticed illustrating that the center of pressure along the X-axis is significantly higher in the left leg than in the right. An excessive increase in the size of movements in the central-lateral direction illustrates an imbalance and muscle weakness, which may increase the risk of joint and muscle damage [24-26]. Balance ability is an important factor in standing, striking combat sports such as boxing. Its weakening along with posture control causes discomfort in the form of pain, and also in-juries, such as instability in the ankle and knee joints, knee osteoarthritis, and acute ankle sprains [24]. Walking stability requires proper mechanical interactions with the environment. During walking, the human body constantly experiences mechanical perturbations caused by motor control errors or environmental factors. Model simulations have shown that minor anterior-posterior disturbances can be stabilized by the body's passive dynamics, while medio-lateral disturbances require active stabilization [27]. Therefore, an in-crease in displacement in the medio-lateral direction in boxing athletes may increase the risk of falling over time and increase the deviation in the joint of the lower limb, especially the ankle. Research analyzing the impact of resistance exercises on body balance in martial arts athletes demonstrated that resistance exercises can effectively improve body balance [28, 29].

Limb symmetry is very important for an athlete's movement [30,31]. Moreover, the presence of symmetry between the dominant and non-dominant leg may counteract muscle imbalance and prevent sports injuries [32,33]. In this study, the participants' gait phase is characterized by a significantly longer swing phase in the right leg, resulting in a shorter single support phase and support phase, compared to the left limb. For the impact of forces, it was observed that the lateral ground reaction force is significantly greater on the left side compared to the right one. Hunzinger et al. [34] studied gait patterns in various sets of athletes and physically active people (including contact sports and non-contact sports) in order to show the impact of collision discipline on the gait pattern. Their analyses found no significant differences in gait parameters between the groups studied [34]. Due to the lack of studies in the field of our own research, i.e. among athletes practicing boxing, a direct comparison is impossible. Inferentially, the irregularities qualitatively demonstrated in our own research may be the result of the directed, specialist boxing profession. Athletes in many years of training and competitive practice, delivering blows from an asymmetric fighting position with the dominant limb (right hand), put a lot of strain on the support limb (left leg) through a twist of the whole body [35]. As a result, the left foot (emphasizing the outer edge) experiences a very strong interaction with the ground. Specialist analyses of kickboxing and boxing fights show the aspect of the quantity and quality of strikes delivered with the dominant limb [36]. In a systematic review, Bellomo et al. found a high risk of post-traumatic encephalopathy in professional boxers, which may significantly affect human motor abilities, including gait [37].

The results of our own research in relation to the remaining diagnosed gait parameters did not show significant differentiation in the profile of limb symmetry. This allows stating that the studied group of boxers presents a correct level of these gait parameters co-occurring with many years of training and competitive experience. Moreover, it suggests the versatility of the applied training process with compensatory-corrective contents, which may have favored the demonstrated level of variables.

The presented study of gait parameters and inter-limb symmetry, in our opinion, has not yet been used in the martial arts environment, and certainly not with personalized diagnosis for boxers. To our knowledge, we are the first to describe the preliminary gait profile of athletes of this profession.

Study Limitations

This research has certain limitations; namely, in this study, selected gait parameters were examined. It is recommended to expand the diagnostics on a larger population and enrich it with kinetic and kinematic variables of other body parts in future research in order to capture a multi-plane clinical context, and thus detailed diagnosis and under-standing of the state of the studied population. In addition, the lack of a control group may make generalizing the results difficult. Finally, in future studies, it is recommended to compare parameters (such as the angles of the lower limb joints muscle torques) of boxing kinematics with other sports, as well as to recognize the co-occurrence of a model gait pattern with training tenure, sports results, and technical-tactical performance.

5. Conclusions

The obtained results showed statistically significant differences for selected parameters of inter-limb symmetry of gait. The identified condition may be related to the influence of specialized training activities of boxing athletes. There is significant asymmetry between the two feet (left and right) in terms of parameters: COPx, swing phase, single support phase, support phase, and cross force reaction of the ground. This asymmetry may result from fighting postures and specialized offensive techniques performed by dominant limbs (greater loads on one side of the body, dominance of the training of the dominant side).

Boxing training does not cause disorders in the remaining studied gait parameters. Athletes do not show significant differences between the dominant and non-dominant leg in terms of inter-limb symmetry and individual gait parameters. This may indicate proper training loads of the lower limbs, in the range of these parameters, which gives hope for the lack of overload injuries related to the aspect of these variables.

Practical Implications

The results can be used for comparative compilations and interpretation of parameters, based on the average values shown in this study. The study parameters can assist in diagnosing and interpreting the gait profile of combat sports athletes, as well as planning therapeutic interventions, if necessary. The results can help coaches and therapists individualize the training process, reducing the risk of abnormalities in the motor system of Boxing athletes. The study confirms the usefulness of the gait profile analysis method for optimizing the quality of coaching control.

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