AIMS Biophysics

AIMS Biophysics, 12(3): 313−332.
DOI: 10.3934/biophy.2025017
Received: 17 April 2025
Revised: 11 July 2025
Accepted: 18 July 2025
Published: 28 July 2025

http://www.aimspress.com/journal/biophysics

Research article

Comparative analysis of straight and hook punches in Sanda Wushu: a kinetic and kinematic study

Soumaya Eltifi-Ghanmi[1,*], Samiha Amara[2,3] and Bessem Mkaouer[2]

[1] Higher Institute of Sport and Physical Education of Sfax, Sfax University, Sfax, Tunisia
[2] Department of Individual Sports, Higher Institute of Sport and Physical Education of Ksar Said, Manouba University, Tunis, Tunisia
[3] Department of Physical Education and Sport Sciences, College of Education, Sultan Qaboos University, Sultanate of Oman

* **Correspondence:** Email: eltifisoumaya.staps@gmail.com; Tel: +21655886461.

Abstract: Sanda, a dynamic combat sport rooted in Wushu, relies on diverse striking techniques for competitive success. This study aimed to compare two fundamental Sanda punches (i.e., the straight punch and the hook punch) through kinetic and kinematic analysis to evaluate their effectiveness in terms of force, speed, and execution dynamics. Nineteen elite Sanda athletes (i.e., 14 males and 5 females) from Tunisia's national team participated in the study. Kinematic data were captured using SkillSpector motion analysis software, while kinetic parameters were calculated through inverse dynamics. Linear and angular kinematics (i.e., displacement, velocity, acceleration, segment angles, and angular velocity) and kinetics (i.e., force, power, linear momentum, and inertia) were assessed. The results revealed significant differences between the punches. The straight punch demonstrated superior execution speed, while the hook punch generated greater force. Kinematically, the straight punch emphasized linear dynamics, whereas the hook punch utilized enhanced angular coordination. These findings highlight distinct biomechanical characteristics; the straight punch excels in rapid linear force transmission, while the hook punch maximizes rotational power. This provides valuable insights for optimizing Sanda training and performance.

Keywords: Sanda; Wushu; motion analysis; kinetics; kinematics; straight punch; hook punch

1. Introduction

Sanda, a combat sport derived from Wushu, is characterized by its dynamic combination of striking techniques (e.g., punches and kicks) and grappling methods (e.g., throws and wrestling), all executed within a designated competition area. As noted by Turner Baker and Miller [1], punching is a complex movement that involves coordinated actions of the arms and legs, as well as the rotational dynamics of the body. To excel in Sanda at the highest competitive level, athletes must possess a diverse range of mental, technical, and physical skills. Consequently, optimizing training requires a comprehensive approach that integrates physiological, psychological, social, genetic, metabolic, muscular, and biomechanical factors.

Despite the growing interest in combat sports, research on Sanda remains limited. Studies by Jiang Olson and Li [2], Shouzheng [3], Siddhartha and Krishnendu [4], and Ye and Qian [5] have contributed valuable insights into the biomechanical aspects of Sanda, shedding light on key performance determinants. However, the field still lacks extensive exploration, particularly in understanding the relationship between speed, strength, and the execution of striking techniques in combat sports. Most existing research has focused on isolated mechanical, physiological, or motor components, leaving a gap in the holistic analysis of Sanda techniques.

Biomechanics, defined as the study of mechanical systems and their application to human movement Moussay [6], plays a critical role in evaluating performance in striking combat sports. Metrics such as net force, acceleration, and speed are commonly used to assess effectiveness, refine training processes, and analyze injury mechanisms. In Sanda, a wide array of techniques, including punches, kicks, sweeps, and throws, must be executed with sufficient force and precision to earn points from referees. Among these techniques, the straight punch (SP) and hook punch (HP) are particularly prominent, yet their biomechanical characteristics remain underexplored compared to techniques in other combat sports, such as boxing [7−9], kickboxing [10,11], taekwondo [12,13], karate [14], and Muay-Thai [15].

According to the Sanda International Competition Arbitration Rules [16], a clean strike to the head awards one point, making punches a critical component of competitive success. Effective execution of these techniques requires not only sufficient force but also precise form, height, and speed. High execution speed, in particular, demands significant force potential to accelerate the body during the strike, while mastery of these techniques necessitates advanced motor coordination, automatism, and spatial synchronization as stated by Ouddak [17]. Gesture control, or the ability to regulate the stages of a movement, is essential for executing Sanda punches with precision and efficiency.

While punches are a fundamental aspect of combat sports, most biomechanical research has focused on boxing techniques such as the jab and cross [7]. In contrast, the unique dynamics of Sanda punches, particularly the SP and HP, have received limited attention. Studies by Piorkowski Lees and Barton [18] and Stanley Thomson Smith et al. [8] have highlighted the need for more comprehensive biomechanical analyses of punching techniques. When compared to other forms of combat sports, Sanda stands out because to its distinctive combination of hitting, takedowns, and the traditional Wushu biomechanics. In contrast to the linear punches used in boxing or the snapping blows used in karate, Sanda methods, such as the SP and HP, rely on a synergistic combination of lower-body force, waist rotation, and precise limb synchronization. These techniques are a reflection of Wushu's notion of whole-body power (zhěng jìn/整劲). As punches frequently transition into throws or defend against kicks, this kinetic chain provides simultaneous force creation and tactical adaptation. Punches commonly transition into throws. In spite of the fact that past research has investigated the dynamics of punching in boxing and kickboxing, Sanda's hybrid character has not been thoroughly studied, particularly with regard to the ways in which its classical Wushu origins impact modern striking efficiency. This research fills that need by presenting the first devoted kinematic and kinetic comparison of SP and HP in elite Sanda athletes. It offers insights that are not only innovative from a scientific standpoint but also useful for coaches and competitors in a practical sense.

In Sanda, the SP is often regarded as one of the most frequently used and effective techniques due to its destructive force and technical utility during competition [19]. However, the comparative effectiveness of SP and HP in terms of speed, force, and overall performance remains unclear.

This study aims to address this gap by conducting a comparative analysis of the SP and HP in Sanda through kinetic and kinematic evaluation. Specifically, we seek to quantify the strength, speed, and efficacy of these techniques and identify which punch is more effective in a competitive context.

Our working hypothesis is that the SP exhibits superior effectiveness, execution speed, and force compared to the HP. By providing a detailed biomechanical comparison, this research aims to enhance the understanding of Sanda techniques and inform training strategies for athletes and coaches.

2. Materials and methods

2.1. Participants

A priori power analysis was conducted with a type I error rate of 0.05 and a statistical power of 90%, utilizing G*Power software (Version 3.1, University of Dusseldorf, Germany; Faul et al., 2009). The analysis demonstrated that at least 19 participants are necessary to detect a significant moderate effect size ($d = 0.70$ and critical $F = 3.259$) for both kinetic (i.e., force, power, inertia, and momentum) and kinematic variables (i.e., velocity, joint, and segment angles) [20,21].

Nineteen volunteer Sanda players from the Tunisian senior national team, consisting of fourteen males (age 21.79 ± 2.33 years; height 1.74 ± 6.25 m; body mass 70.06 ± 11.28 kg; training average 20 h/week; experience 10.36 ± 4.75 years of practice) and five females (age 22.40 ± 3.36 years; height 1.63 ± 7.40 m; body mass 60.94 ± 7.37 kg; training average 20 h/week; experience 7.40 ± 2.70 years of practice) volunteered to participate in this study. The subjects were in excellent health and did not suffer from any neurological, muscular, or tendon injuries.

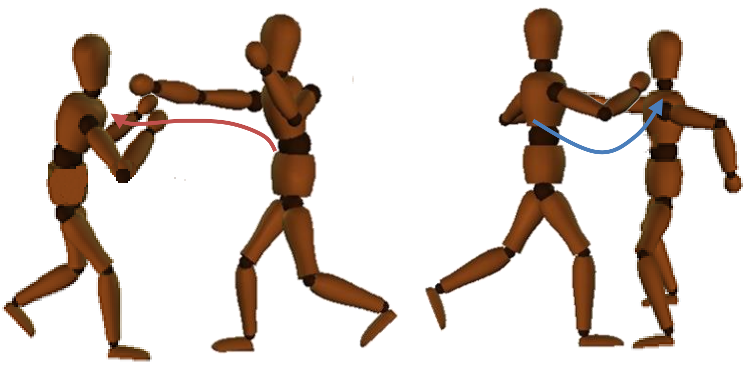
2.1.1. Ethics approval of research

After Each participant consented to participate in the research by completing a permission form after being thoroughly briefed about the processes, methodologies, possible benefits, and associated hazards of the study beforehand. The trial was executed in accordance with the Declaration of Helsinki and received approval from the Ethical Committee of the National Observatory of Sport (ONS/UR/18JS01).

2.2. Experimental design and procedures

A 3D kinematic analysis of two punches in Sanda specifically, SP and HP, was conducted to investigate differences in strength, speed, and power indices when these punches were executed on a punching bag (see Figure 1a and 1b). All participants performed the punches under standardized conditions, adopting an orthodox stance with feet positioned at 1.5 times shoulder width (lead foot at 30°, rear foot at 15°) and maintaining a 70/30% weight distribution between the rear and front legs.

At the start of each experimental session, participants completed a ten-minute warm-up consisting of stretching exercises for the trunk and lower limbs.



(a) **(b)**

Figure 1. The two studied Sanda Wushu punches; (a) SP; (b) HP.

Before the test begins, the participants will be briefed about the apparatus and the procedure that will be followed during the experiment. Throughout the course of the experiment, the volunteers will be given standardized instructions, and they will also get verbal encouragement to urge them to reach their highest possible levels of performance.

Figure 2. Experimental design.

The participant positions himself on the mat before two cameras (one frontal and the other lateral, 3 meters from the bag), adorned with 20 low-mass retro-reflective markers affixed to his body. The dominant arm will be evaluated in each assessment. The expert positions himself before a punching bag and executes each category of arm punches thrice in a randomized sequence (e.g., SP and HP), allowing for a 30-second recovery between repetitions and a two-minute interval between punch categories for each session (e.g., two sessions over two days from 2 p.m. to 4 p.m.) (Figure 2).

The experts perform each punch on the punching bag three times prior to the test in order to calibrate their evolution to execute the kicks at a precise point marked on the bag. The kinematic data were subsequently recorded using two ACME Sports & Action Cameras (VR301 4K; full HD; f/2.2 lens; 120Hz). The free software Virtual Dub version 1.10.4 will be employed to decode the video (Kim et al., 2010). Data digitization through the utilization of the free software SkillSpector® (Geeware, Version 1.3.2, Svendborg, Denmark [22−24]), (Figure 3).

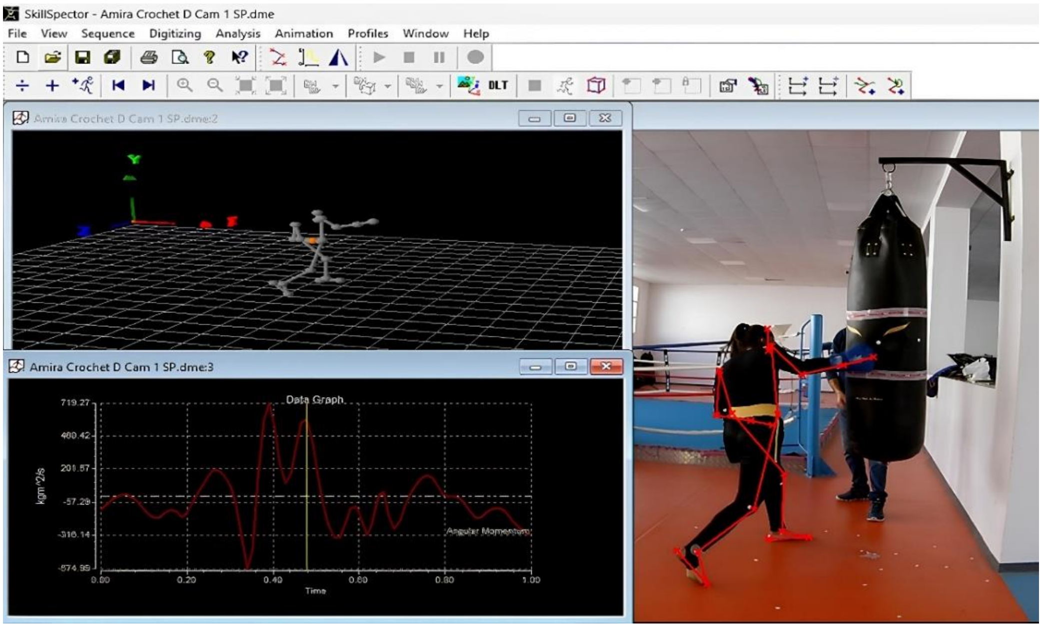


Figure 3. Digitalization with SkillSpector software.

The biomechanical model that will be used is the one that was developed by Hanavan (1964) and then updated by de Leva (1996). This fundamental architecture is made up of twenty points and fourteen segments that are dispersed around the body. Curiosity Labs, Inc., Poser 4.0.3 version will be responsible for the development of the building of critical locations as well as 3D Kinograms. For the purpose of calculating force using inverse dynamics, the formula developed by [25] is used (Equation 1a and 1b; Figure 4).

$$(a)\ \ I = \frac{mL^2}{3} + md^2 \ \ (b)\ \ F = \frac{2I\theta}{Ttd} \tag{1}$$

In this context, I represents inertia, F denotes the striking force, m signifies the mass of the punching bag, L indicates the length of the punching bag, d refers to the distance between the hanging point and the center of mass of the punching bag, θ represents the rotational angle of the punching bag, T is the duration of contact with the punching bag, and t denotes the movement time of the punching bag (Figure 5).

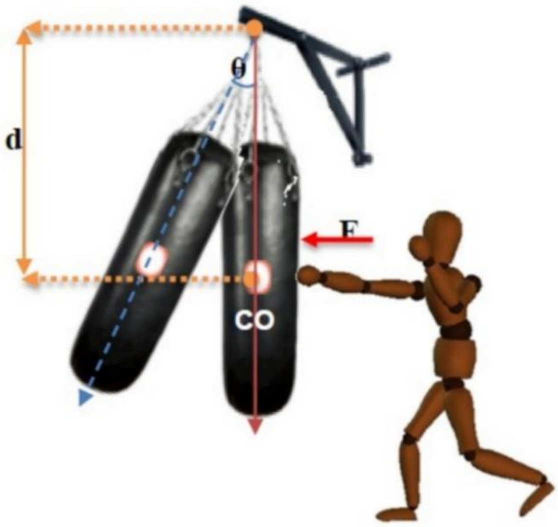


Figure 4. Calculation of force by inverse dynamics [25].

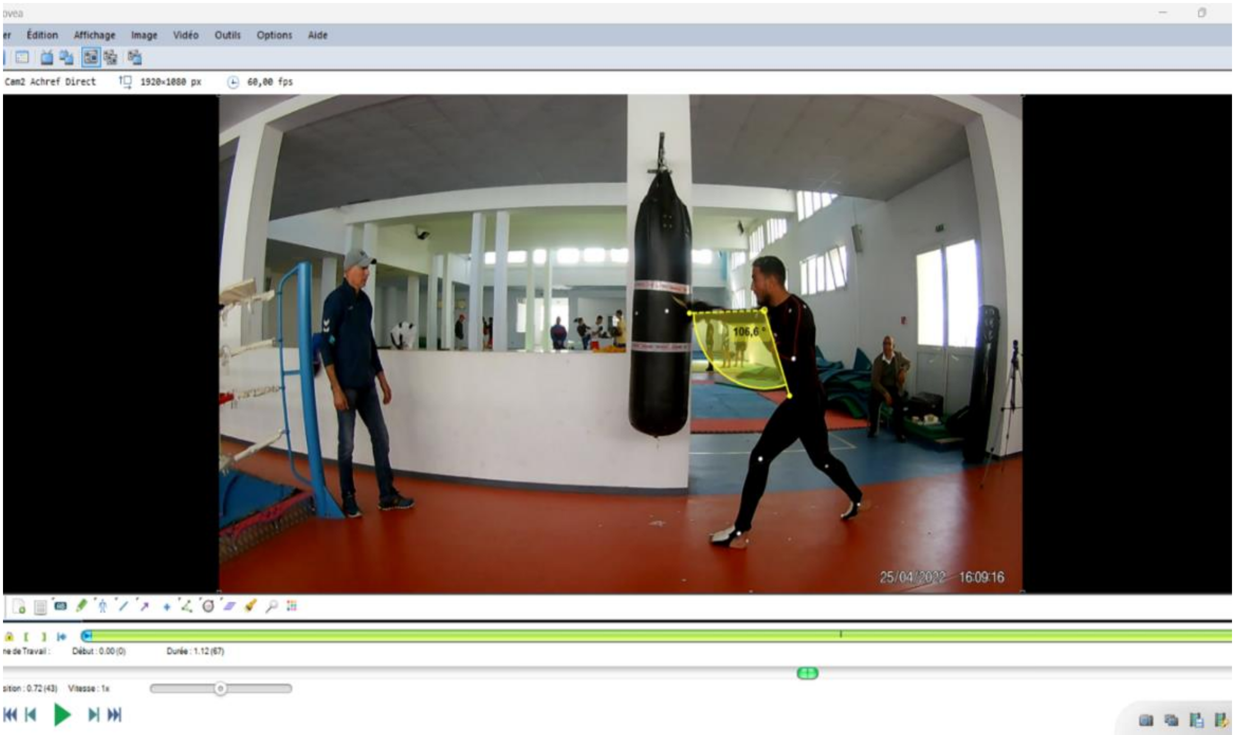


Figure 5. Calculating angles with Kinovea software.

For the calculation of the punching bag COM, two methods were used: the mass pendulum method and the two-point barycenter formula for a semi-rigid cylinder, in which the supporting metal chain was included in the calculation.

The barycenter coordinates were determined as follows (Equation 2a and 2b):

$$(a)\ xG = (a * xA + b * xB) / (a + b)\ (b)\ yG = (a * yA + b * yB) / (a + b) \quad (2)$$

Where:

- *a* and *b* are the masses of the two components (e.g., the punching bag and the chain),
- *xA*, *yA* and *xB*, *yB* are the coordinates of the centers of mass of each component.

2.3. Statistical analysis

The data analysis utilized SPSS 25 software (SPSS, Chicago, IL, USA) for statistical evaluation. Data are presented as mean ± standard deviation (SD) along with 95% confidence intervals (95% CI). Effect size (d) was determined utilizing G*Power software (Faul et al., 2009). The interpretation of *d* was based on the following scale: < 0.2 (trivial); 0.2–0.6 (small); 0.6–1.2 (moderate); 1.2–2.0 (large); and > 2.0 (very large) [26,27]. The Shapiro-Wilk test indicated that the distribution normality was satisfactory for all variables. Consequently, a paired T-test was utilized to compare the various punches in Sanda Wushu (i.e., SP and HP). The relative and absolute reliability of punching forces, specifically in SP and HP, were assessed using the intraclass correlation coefficient (ICC) and the typical error of measurement (TEM), represented as the coefficient of variation (CV). The SWC was calculated by multiplying the between-subject standard deviation by 0.2 (SWC0.2), representing a typical small effect [28]. The test's capacity to identify a change was classified as "good", "OK", or "marginal" based on whether the TEM was below, comparable to, or above SWC0.2, respectively[29]. The minimal detectable change (MDC95%), indicating the 95% confidence interval of the score difference between paired observations, was calculated as MDC95% = TEM 1.96 √2 [30] . The significance level was established at $p < 0.05$.

3. Results

The inverse dynamics measurements of punching force for both SP and HP demonstrated high levels of absolute and relative reliability. The results, as shown in Table 1, demonstrated high levels of absolute and relative reliability of force measurements across two repetitions (R1 and R2) for both punch types (i.e., SP and HP).

Table 1. Absolute and relative reliability of force measured for three kicks in Sanda.

R_1 vs. R_2		Mean ± SD	T-test (*p*)	TEM	TEM $_{(\%)}$	MDC $_{(95\%)}$	SWC $_{(0.2)}$	ICC $_{(95\%\ CI)}$
Force (N/kg)	SP $_{R1}$	1.79 ± 0.83	0.180	0.01	0.388	0.019	0.490	0.996 (0.988−0.998)
	SP $_{R2}$	1.82 ± 0.83						
	HP $_{R1}$	2.14 ± 0.34	0.328	0.02	0.767	0.046	0.207	0.976 (0.938−0.991)
	HP $_{R2}$	2.16 ± 3.36						

(SP) Straight Punches; (HP) Hook Punches; (R1) First repetition; (R2) Second repetition; (TEM) Typical error of measurement; (MDC) Minimal detectable change; (SWC) Smallest worthwhile change; (ICC) Intra-class correlation coefficient.

The kinetics analysis between punch technics outlined in Table 2 indicates that the T-test revealed significant differences across several parameters in Sanda. Specifically, highlighted notable variations in power (Pt), linear momentum (LM), and angular momentum (AM), all of which showed a high statistically significant difference ($p < 0.001$).

In contrast, force (Ft) and momentum of inertia (MI) did not show significant differences ($p > 0.05$).

Table 2. T-test of punching kinetics parameters in Sanda.

Source	Mean Diff.	SD Diff.	SE Diff.	t	df	Sig.	Effect Size
Ft	−2.170	7.158	1.642	−1.321	18	0.203	0.303
Pt	−52.833	31.726	7.278	−7.259	18	0.000**	1.665
LM	21.149	10.486	2.406	8.792	18	0.000**	2.016
AM	599.676	145.251	33.323	17.996	18	0.000**	4.128
MI	−0.122	1.163	0.267	−0.457	18	0.653	0.104

(Ft) Force; (Pt) Power; (LM) Linear momentum; (AM) Angular momentum; (MI) Moment of inertia; (*) significant at $p < 0.050$; (**) significant at $p < 0.010$.

Concerning linear kinematics analysis between punch technics, the T-test (Table 3) showed significant variance across all parameters except vertical displacement and velocity of the COM, horizontal velocity of the elbow and vertical acceleration of the head.

Table 3. T-test of punching linear kinematics parameters in Sanda.

Source	Mean Diff.	SD Diff.	SE Diff.	t	df	Sig.	Effect Size
Imp_{Time}	0.013	0.022	0.005	2.616	18	0.018*	0.590
$Exec_{Time}$	−0.093	0.045	0.010	−9.027	18	0.000**	2.066
dx_{COM}	0.036	0.069	0.016	2.297	18	0.034*	0.521
dy_{COM}	−0.002	0.028	0.006	−0.257	18	0.800	0.071
Vx_{COM}	0.189	0.203	0.047	4.056	18	0.001**	0.931
Vy_{COM}	0.028	0.140	0.032	0.868	18	0.397	0.2
Vt_{COM}	0.246	0.207	0.048	5.185	18	0.000**	1.188
$Vx_{Shoulder}$	0.835	0.659	0.151	5.518	18	0.000**	1.267
$Vy_{Shoulder}$	0.144	0.286	0.066	2.191	18	0.042*	0.503
$Vt_{Shoulder}$	0.881	0.663	0.152	5.791	18	0.000**	1.328
Vx_{Elbow}	−0.044	1.057	0.243	-0.180	18	0.859	0.04
Vy_{Elbow}	1.298	0.661	0.152	8.556	18	0.000**	1.963
Vt_{Elbow}	0.729	1.286	0.295	2.470	18	0.024*	0.566
Vx_{Wrist}	−2.334	1.039	0.238	−9.790	18	0.000**	2.246
Vy_{Wrist}	−1.118	0.588	0.135	−8.285	18	0.000**	1.901
Vt_{Wrist}	−1.797	0.849	0.195	−9.223	18	0.000**	2.116
Vx_{Finger}	−1.875	1.172	0.269	−6.975	18	0.000**	1.599
Vy_{Finger}	−1.813	0.930	0.213	−8.497	18	0.000**	1.949
Vt_{Finger}	−2.119	0.991	0.227	−9.319	18	0.000**	2.138

Continued on next page

Source	Mean Diff.	SD Diff.	SE Diff.	t	df	Sig.	Effect Size
Ax_{Finger}	−57.841	23.284	5.342	−10.828	18	0.000**	2.484
Ay_{Finger}	−47.894	18.198	4.175	−11.472	18	0.000**	2.631
At_{Finger}	−75.560	23.921	5.488	−13.769	18	0.000**	3.158
Ax_{Head}	0.219	0.185	0.043	5.158	18	0.000**	1.183
Ay_{Head}	−0.071	0.160	0.037	−1.950	18	0.067	0.443
At_{Head}	0.107	0.153	0.035	3.031	18	0.007**	0.699

(Imp_{Time}) Impact time; (Exetime) Execution time ; (COM) Center of mass; (dx_{COM}) Horizontal displacement; (dy_{COM}) Vertical displacement; (Vx_{COM}) Horizontal velocity; (Vy_{COM}) Vertical velocity; (Vt_{COM}) Total velocity; Horizontal velocity of the Shoulder; ($Vx_{Shoulder}$) Vertical velocity of the toe; ($Vy_{Shoulder}$) Total velocity of the toe ($Vt_{Shoulder}$); Horizontal velocity of the Elbow; (Vx_{Elbow}) Vertical velocity of the Elbow; (Vy_{Elbow}) Total velocity of the Elbow (Vt_{Elbow}); Horizontal velocity of the Wrist; (Vx_{Wrist}) Vertical velocity of the Wrist; (Vy_{Wrist}) Total velocity of the Wrist (Vt_{Wrist}); Horizontal velocity of the Wrist; (Vx_{Wrist}) Vertical velocity of the Wrist; (Vy_{Wrist}) Total velocity of the Wrist (Vt_{Wrist}); Horizontal velocity of the Finger; (Vx_{Finger}) Vertical velocity of the Finger; (Vy_{Finger}) Total velocity of the Finger (Vt_{Finger}); Horizontal velocity of the Head; (Vx_{Head}) Vertical velocity of the Head; (Vy_{Head}) Total velocity of the Head (Vt_{Head}); (*) significant at $p < 0.050$; (**) significant at $p < 0.010$.

For angular kinematics analysis between punch technics, results (Table 4) showed significant differences among all angular kinematic parameters except wrist angle and angular velocity of the shoulder joint.

Table 4. T-test of punching angular kinematics parameters in Sanda.

Source	Mean Diff.	SD Diff.	SE Diff.	t	df	Sig.	Effect Size
$Ang_{Shoulder}$	5.865	11.495	2.637	2.224	18	0.039*	0.510
Ang_{Elbow}	13.111	9.979	2.289	5.727	18	0.000**	1.313
Ang_{Wrist}	1.253	5.497	1.261	0.993	18	0.334	0.227
$AngV_{Shoulder}$	−50.526	853.638	195.838	−0.258	18	0.799	0.05
$AngV_{Elbow}$	897.469	935.653	214.654	4.181	18	0.001**	0.959
$AngV_{Wrist}$	−108.283	137.526	31.551	−3.432	18	0.003**	0.787
$AngV_{Upp\text{-}Arm}$	−843.663	226.759	52.022	−16.217	18	0.000**	3.720
$AngV_{Fore\text{-}Arm}$	−276.672	99.044	22.722	−12.176	18	0.000**	2.793
$AngV_{Hand}$	−282.094	120.769	27.706	−10.182	18	0.000**	2.335
$AngV_{Head}$	−43.100	25.695	5.895	−7.311	18	0.000**	1.677

($Ang_{Shoulder}$) Shoulder angle; (Ang_{Elbow}) Elobow angle; (Ang_{Wrist}) Wrist angle; ($AngV_{Shoulder}$) Shoulder angular velocity; ($AngV_{Elbow}$) Elobow angular velocity; ($AngV_{Wrist}$) Wrist angular velocity; ($AngV_{Upp\text{-}Arm}$) Upper-Arm angular velocity; ($AngV_{Fore\text{-}Arm}$) Fore-Arm angular velocity; ($AngV_{Hand}$) Hand angular velocity; ($AngV_{Head}$) Head angular velocity; (*) significant at $p < 0.050$; (**) significant at $p < 0.010$.

For the two punching techniques (i.e., SP and HP), Figure 6 offers correspondingly a graphical depiction of the variations in force (Figure 6a), speed (Figure 6b) and power (Figure 6c).

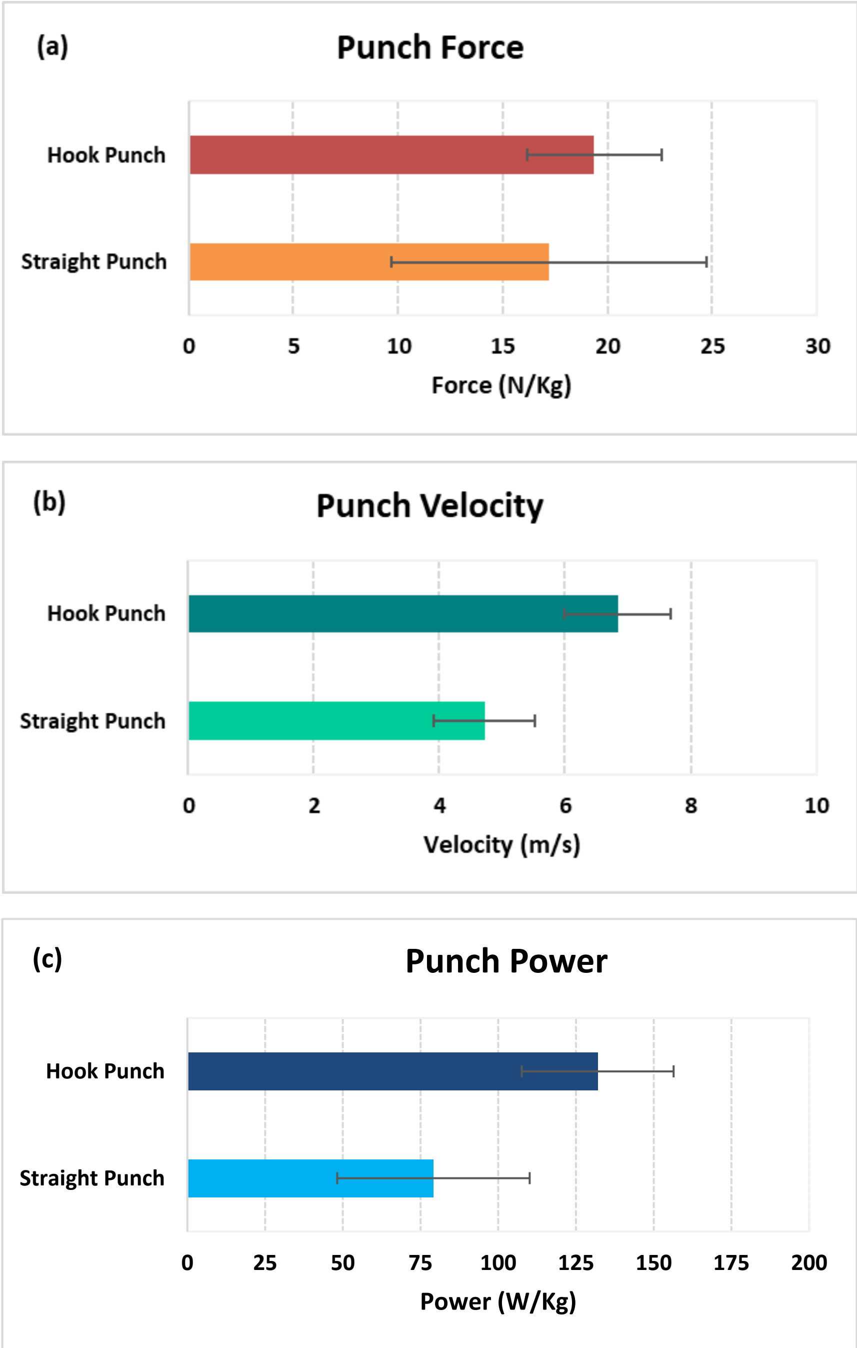


Figure 6. Variation of force, velocity and power of the SP and HP: (a) Force; (b) Velocity; (c) Power.

4. Discussion

The purpose of this research is to examine two Sanda punch methods (i.e., HP and SP) and to draw comparisons between their kinematic and kinetic analyses. A total of 19 Sanda players (14 men and 5 women) from Tunisia's senior national squad volunteered to take part in the research.

The results confirm the reliability of kinetic and kinematic measurements in Sanda punches, with high ICC values (0.976–0.996) and minimal variability ($p > 0.05$), providing a robust framework for performance analysis, training optimization, and punch improvement in Sanda.

Within the scope of this investigation, the kinetic analysis of the two punches in Sanda considers five significant aspects: Ft, Pt, LM, AM, and MI. A highly significant disparity is evident in Pt, LM, and AM, with ($p < 0.001$).

The kinetic analysis reveals fundamental differences between SP and HP, demonstrating distinct mechanical profiles that extend beyond mere technical execution. Most notably, HP exhibits significantly greater specific power output with 131.982 ± 24.420 W/kg compared to SP 79.148 ± 30.956 W/kg, $p < 0.001$, attributable to its rotational mechanics involving greater trunk and hip engagement.

While HP produces demonstrably higher power, its nonsignificant advantage in peak force ($p = 0.203$) is most likely due to basic biomechanical differences between rotational and linear approaches. HP's rotational mechanics distribute power over a longer execution time (0.348 ± 0.03s vs 0.255 ± 0.05s for SP, $p < 0.001$, $d = 2.06$) and utilize more gradual force transfer through enhanced trunk stability, as evidenced by its significantly lower linear momentum (19.358 ± 6.539 kg·m/s vs 40.507 ± 12.677 kg·m/s for SP, $p < 0.001$, $d = 2.16$). This trend is consistent with results in other combat sports in which rotating blows emphasize continuous energy transfer over peak power [30]. The significant impact size for angular momentum ($d = 4.128$) strongly supports this mechanical difference, while we accept that further research with bigger samples may substantiate these results. While our 3D kinematic approach provides reliable within-technique comparisons (ICC 0.976−0.996), it may understate the three-dimensional force components in HP's curved trajectory, a limitation that suggests promising avenues for future research combining 3D motion capture with direct force measurements.

The observed differences arise from Sanda's specific competitive demands, necessitating a transition from strikes to throws. HP's power generation is moderated by the requirement to sustain balance for subsequent grappling, as indicated by its controlled angular momentum of 152.780 ± 32.628 kg·m²·rad/s. In contrast, SP's linear mechanics, with a momentum of 40.507 ± 12.677 kg·m/s, emphasize scoring speed for head strikes in accordance with the Federation [16] ruleset.

As demonstrated by Xu Mao and Xi [31] in their study of Wushu athletes, enhanced trunk rotation significantly contributes to swing speed and power generation in rotational strikes. This aligns with VencesBrito Rodrigues-Ferreira Cortes et al. [32] findings in karate, where reverse punches showed greater force generation than direct punches due to rotational mechanics. Similarly, Filimonov Koptsev Husyanov et al. [33] observed in boxing that rotational punches like hooks punches, produce higher impact forces.

LM, calculated as mass multiplied by linear velocity, represents a critical kinetic determinant of striking efficacy in Sanda Wushu. Our comparative analysis revealed SP generates significantly greater LM 40.507 ± 12.677 kg·m/s than HP 19.358 ± 6.539 kg·m/s, $p < 0.001$, demonstrating its mechanical advantage for direct energy transfer through linear trajectory. This finding precisely corroborates Beránek Votápek and Štastný [34] analysis of taekwondo strikes, where similar linear techniques showed superior momentum transfer efficiency compared to rotational strikes, confirming the biomechanical principle that straight trajectories optimize impulse generation in combat sports. This explains SP's effectiveness for fast, long-range strikes. While HP's circular motion reduces LM through angular components, it maintains tactical value for destabilizing opponents, consistent with Gulledge and Dapena [35] findings about punch variations in combat sports. Dinu and Louis [36] boxing research further validates this dichotomy, showing linear techniques optimize energy transfer while rotational strikes serve distinct tactical purposes.

The final crucial kinetic factor in evaluating punches in Sanda is AM. In fact, the analysis of this component further highlights this dichotomy: SP shows significantly higher values with 752.456 ± 136.47 kg·m²·rad/s vs 152.780 ± 32.628 kg·m²·rad/s for HP, $p < 0.001$, indicating superior trunk rotation utilization for direct strikes. HP employs more controlled rotation, prioritizing precision over raw power as demonstrated by Dinu Millot Slawinski et al. [37] in their examination of boxing techniques, where hooks showed more controlled rotation patterns compared to SPs.

The diverse biomechanical characteristics of SP and HP develop as direct responses to Sanda's specific competitive limitations. The SP's high execution speed (0.255 ± 0.05 s) and controlled linear momentum (40.51 ± 12.68 kg·m/s) align with the sport's scoring system, which promotes rapid accurate head strikes while requiring prompt defensive recovery to prevent counter-scoring. The HP's balance of rotational power (131.98 ± 24.42 W/kg) and moderated angular momentum (152.78 ± 32.63 kg·m²·rad/s) meets Sanda's hybrid strike-throw requirements, generating enough force for point eligibility while maintaining the sub-3-second transition window required for throw attempts. This kinetic tradeoff contrasts significantly from boxing hooks, where unlimited rotation enhances punch power while ignoring throw concern. Both methods include defensive measures against Sanda's kick-focused ruleset. SP maintains a low center-of-mass displacement (21.08 ± 5.27 mm) for kick defense, while HP's quick distal acceleration (164.30 ± 21.93 m/s²) provides contact certainty before escape. These changes show how Sanda's ruleset has created a biomechanical profile unknown in punch-dominant combat sports.

It is via these biomechanical characteristics that Sanda training is directly informed: demonstrates enhanced counterattacking efficiency against linear strikes, such as kicks, with a superior speed of 0.255 ± 0.05 s. In contrast, HP's power of 131.98 ± 24.42 W/kg and controlled rotation of 152.78 ± 32.63 kg·m²·rad/s are optimized for close-range engagements, facilitating transitions from strikes to throws. While 3D analysis may slightly underestimate curved trajectories, particularly HP's distal acceleration at 164.30 ± 21.93 m/s², this effect is consistent across techniques and maintains comparative validity, as evidenced in karate kinematics research [32].

These findings underscore the strategic complementarity of both techniques in combat situations. For Sanda practitioners, this suggests the need to specifically develop segmental coordination for HP while refining linear mechanics for SP, with particular emphasis on optimizing trunk rotation as highlighted by [31] in Wushu training. The mastery of these two techniques, though distinct in their characteristics, remains equally essential for optimizing a fighter's offensive repertoire. The tactical combination of these punches, deployed according to combat circumstances, would enhance overall fighting effectiveness by leveraging their respective strengths in power generation HP and direct energy transfer SP.

In light of our kinematic and kinetic results, we recommend targeted training strategies for Sanda practitioners. In SP development, coaches must to use speed-centric exercises with medicine ball throws (2−4kg), prioritizing full elbow extension (163.75 ± 5.98°) and swift execution (aiming for a movement time of 0.255 ± 0.05s). HP training must emphasize the development of rotational power by resisted trunk rotations and whip-like towel exercises to improve distal segment acceleration, aiming for 164.30 ± 21.93 m/s². These workouts specifically target the biomechanical disparities revealed in our research. Future study should examine muscle activation patterns via EMG analysis, specifically during the chán sī jìn kinetic chain of HP execution, and analyze ideal punch combinations inside Sanda's distinctive 3-second throw transition interval.

The kinematic analysis revealed fundamental differences in execution patterns between SP and

HP. In fact, SP demonstrated significantly shorter execution time with 0.255 ± 0.05 sec compared to HP with 0.348 ± 0.03 sec, $p < 0.001$, attributable to its linear trajectory reducing movement distance. This speed advantage aligns with Sanda's scoring system that rewards rapid, clean head strikes, while HP's longer execution facilitates the preparatory weight transfer needed for throw combinations a tactical requirement absents in boxing. While execution time has not been previously examined for punching techniques in combat sports, this finding aligns with Falco Alvarez Castillo et al. [38] observations in taekwondo kicking techniques, where shorter movement paths correlated with reduced execution times.

The markedly higher finger acceleration in HP (164.304 ± 21.93 m/s²) compared to SP (88.744 ± 9.65 m/s², $p < 0.001$) underscores the critical role of distal segment dynamics in rotational techniques and reflects Wushu's chán sī jìn (silk-reeling energy) principles, where distal segment whipping complements rotational power generation while preserving balance a dual imperative unique to Sanda's strike-throw hybridization. This value derived from our kinematic analysis of elite Sanda athletes exceeds typical measurements in boxing hooks (~120 m/s²; [9]), likely reflecting Wushu's emphasis on chán sī jìn (silk-reeling energy) and whole-body coordination. This adaptation allows Sanda practitioners to generate whipping-like terminal velocity while maintaining control for subsequent throw transitions, a unique requirement absent in boxing.

Impact characteristics showed distinct force transfer mechanisms between techniques. SP exhibited longer impact time 0.05 ± 0.02 sec than HP with 0.04 ± 0.01 sec, $p < 0.05$, consistent with Mosler Kacprzak and Wąsik [39] findings regarding body rigidity variations during contact. The briefer but more explosive interaction in SP corresponds with Bingül Bulgan Tore et al. [40] measurements of faster energy release in linear strikes, while HP's prolonged contact facilitates more gradual force transfer through enhanced trunk stability. These force transfer patterns are further supported by Smith Dyson Hale et al. [41] dynamometric measurements of punching forces in elite boxers, where maximum forces reached 4800N values that inherently require the rapid segmental accelerations observed in our study.

Segmental velocity profiles revealed technique-specific advantages, with SP generating greater proximal segment velocities in shoulder 2.045 ± 0.56 m/s and in elbow: 5.304 ± 1.01 m/s, $p < 0.001$) while HP produced superior distal velocities in wrist: 7.182 ± 0.82 m/s and in fingers: 6.838 ± 0.85 m/s, $p < 0.001$). These findings extend Abazari and Rostami [42] work on joint torque distribution and are partially supported by Wąsik Góra Ortenburger et al. [43] observations of wrist velocity differences between punch types with the SP (9.37 m/s) higher than with the HP (8.79 m/s), although the difference is not very significant ($p = 0.13$). This emphasizes that SP is faster. Notably, HP demonstrated substantially greater finger acceleration with 164.304 ± 21.93 m/s² vs SP's 88.744 ± 9.65 m/s², $p < 0.001$, emphasizing the importance of distal segment dynamics as highlighted by Tong-Iam Rachanavy and Lawsirirat [15] research on forearm-finger synchronization in striking techniques.

Center of mass displacement analysis showed greater horizontal movement in HP with 24.71 ± 6.85 mm compared to SP with 21.08 ± 5.27 mm, $p < 0.05$, confirming Piorkowski Lees and Barton [18] findings of enhanced body mobilization in rotational strikes. This represents a strategic adaptation where HP's off-axis loading prepares throw initiation, contrasting with boxing hooks that prioritize maximal rotation. This is facilitated by Sanda's characteristic wider stances (visually confirmed in our video analysis as markedly wider than boxing's orthodox position), which enhance rotational power without compromising stability against kicks - a critical defensive consideration given Sanda's rules permitting low kicks. This increased segmental displacement contributes to HP's kinetic energy transfer while potentially compromising defensive positioning, as evidenced by greater head acceleration in SP with 0.628 ± 0.15 m/s² vs HP's 0.521 ± 0.09 m/s², $p < 0.01$, consistent with Echeverria and Santos [14] risk assessment of head movement during punching.

The collective kinematic data demonstrates that SP and HP employ fundamentally different mechanical strategies, with SP optimizing speed and linear force transfer while HP emphasizes rotational body engagement and distal segment acceleration. The findings have direct implications for Sanda training and competition strategies. Initially, SP's rapid execution (0.255 ± 0.05s) and linear efficiency (40.51 ± 12.68 kg·m/s) are essential for scoring under the 1-point head strike rule. In contrast, HP's rotational power (131.98 ± 24.42 HP exhibits W/kg) and controlled momentum (152.78 ± 32.63 kg·m²·rad/s) enhance throw setups within the 3-second transition period. HP's whip-like distal acceleration (164.30 ± 21.93 m/s²) supports the efficacy of traditional Wushu chán sī jìn drills in sustaining balance during strike-throw combinations. Coaches ought to integrate these biomechanical insights with Sanda's specific rules, employing SP defensively against kicks (21.08 ± 5.27mm COM stability) and HP offensively to generate throwing opportunities (24.71 ± 6.85 mm COM displacement). Three key distinctions arise when contextualizing these findings: first, the kinetic trade-offs between striking power and throw preparedness; second, the rule-driven optimization that balances linear speed with rotational control; and third, the adaptations of traditional Wushu stances that facilitate unique force generation strategies. Together, they elucidate why direct boxing comparisons [33] do not adequately represent Sanda's technical characteristics—specifically, HP's dual focus on high distal acceleration (164.3 m/s²) and moderated angular momentum (152.8 kg·m²·rad/s), which collectively enable its hybrid strike-throw capability.

These findings have important implications for technical training in Sanda, suggesting the need for specialized development of both linear and rotational striking mechanics to address diverse combat scenarios. The distinct velocity and acceleration profiles at different segmental levels provide empirical support for the complementary application of these techniques in competition.

The angular kinematic analysis reveals fundamental differences in joint mechanics between SP and HP, elucidating their distinct biomechanical profiles. SP demonstrated significantly greater shoulder angles with 105.04 ± 11.10° vs HP's 99.17 ± 7.38°, $p < 0.05$ and elbow extension with 163.75 ± 5.98° vs 150.63 ± 7.94°, $p < 0.001$, suggesting more complete joint utilization in linear strikes and reflecting technique-specific adaptations to Sanda's tactical ecosystem: SP's full extension maximizes reach for scoring-oriented head strikes, while HP's moderated extension preserves the joint mobility needed for rapid post-strike grappling transitions, a biomechanical compromise unseen in boxing hooks. These findings align partially with Xu Mao and Xi [31] in a comparative study of Sanda and boxing techniques, though their reported shoulder angles with 65.32 ± 2.38° in Sanda and 64.21 ± 3.22° in boxing, were notably lower, potentially indicating sport-specific adaptations. The elbow extension patterns corroborate Stanley Thomson Smith et al. [8] observations of greater extension in SP with 135.4 ± 12.3° vs HP with 121.6 ± 10.2°, while contrasting with Rinaldi Nasr Atef et al. [44] in karate data with 85.4° in Junzuki techniques, highlighting discipline-specific kinematic variations.

Building on previous research in biomechanics, key works by Piorkowski Lees and Barton [18] and Stanley Thomson Smith et al. [8] set important standards for punch biomechanics in boxing, though their results were naturally limited to Western boxing. While Piorkowski Lees and Barton [18] examined isolated jab/cross techniques in novice participants, Stanley Thomson Smith et al. [8] used advanced 3D analysis methods to look at amateur fighters' punch combinations. Both groups specifically asked for more research to be done on other hitting sports. Our study immediately fills in this gap by measuring Sanda Wushu's signature methods biomechanically for the first time. We show how the SP combines linear boxing-like kinetics with Wushu-specific trunk rotation. The HP, on the other hand, uses special silk-reeling rotational mechanics (chán sī jìn) to make more force than SP by separating the hips and shoulders in synchronization. These results greatly expand the field of boxing-focused biomechanics by identifying the sport-specific kinetic chains of traditional martial arts. They also give coaches evidence-based training metrics for SP/HP optimization and set up a framework for future research across striking disciplines like Sanda and Muay Thai.

Inter-segmental coordination analysis revealed pronounced differences in rotational velocities across body segments with elbow: $p < 0.001$; wrist: $p < 0.01$ and upper arm/forearm/hand/head: $p < 0.001$). These results are supported by Xu Mao and Xi [31] documentation of shoulder angular velocities with 12.95 ± 1.12 rad/s in Sanda and 11.55 ± 1.23 rad/s in boxing and Dinu and Louis [36] findings that shoulder contribution accounts for 50.1 to 71% of hook/uppercut power. The distal segment dynamics are further evidenced by Mosler Kacprzak and Wąsik [9] report of greater wrist acceleration in rear punches with 94.33 m/s² vs SP's 66.07 m/s², consistent with our observed distal velocity patterns. However, Piorkowski Lees and Barton [18] observation of speed reduction during consecutive strikes with 9.26 ± 2.09 m/s which decreased to 7.49 ± 2.32 m/s suggests potential fatigue effects not captured in our single-strike analysis.

The combined evidence demonstrates that SP and HP employ fundamentally different joint angle strategies, with SP maximizing extension for linear force transfer while HP utilizes controlled flexion for rotational power generation. These differences are further influenced by body posture factors, as noted by Bingül Bulgan Tore et al. [40] work on trunk angle importance reporting an average of 19.2° ± 3.4° in orthodox stance, and VencesBrito Rodrigues-Ferreira Cortes et al. [32] documentation of efficient distal energy transfer that observed a maximum hand speed of 9.12 ± 1.34 m/s during a karate strike. The kinematic profiles suggest that while SP optimizes joint extension for direct force application, HP sacrifices full extension to enable the rotational mechanics critical for bypassing defenses and generating torque.

Although the kinematic differences between linear and rotational strikes are well-documented in combat sports, our findings indicate Sanda-specific adaptations that question established paradigms. The SP demonstrates a superior speed (0.255 ± 0.05s) while exhibiting a non-significant peak force advantage ($p = 0.083$) compared to HP. This indicates that Sanda's scoring rules emphasize rapid precision rather than raw power, highlighting a significant difference from boxing dynamics. HP demonstrates remarkable distal acceleration (164.30 ± 21.93 m/s²), surpassing both SP and conventional boxing hooks, underscoring the impact of Wushu's chán sī jìn principles on power generation. The findings, combined with HP's distinctive kinetic balance between rotational power (131.98 W/kg) and throw-ready balance (152.78 kg·m²·rad/s), illustrate how Sanda's competitive constraints generate biomechanical profiles that are unmatched in striking-focused sports. Future EMG analyses of kinetic chains or comparative studies among Wushu styles may provide greater insight into these adaptations.

It is important to recognize several methodological considerations. Our sample comprised elite athletes ($N = 19$); however, the gender imbalance (14 male vs. 5 female participants) may limit the generalizability of findings to female Sanda practitioners. Future research should emphasize gender-balanced recruitment. Also, our 3D kinematic analysis exhibits high reliability (ICC 0.976−0.996), yet it may underestimate the three-dimensional aspects of HP's curved trajectory; comprehensive kinetic profiles would be better captured through full 3D motion capture. The single-strike paradigm works to control fatigue; however, it fails to represent competitive combinations. Future research should focus on analyzing punch sequences. These limitations similarly impacted both techniques, thereby maintaining their comparative validity. Future research should validate these results by integrating 3D kinematic analysis with force sensors on the punching bag, in larger, gender-balanced samples while performing competitive punching combinations.

These findings have important implications for Sanda training methodologies, suggesting the need for technique-specific development of both maximal joint extension for SP and controlled flexion-rotation coordination for HP. The angular kinematic differences further explain the observed variations in strike effectiveness, with SP's biomechanics favoring speed and direct force transfer, while HP's mechanics enhance rotational power and tactical versatility.

5. Conclusions

The biomechanical analysis of the SP and HP in Sanda Wushu highlights distinct strategic and functional differences between the two techniques. The SP is characterized by its efficiency in linear force transmission, enabling rapid and precise execution. In contrast, the HP leverages enhanced angular dynamics and inter-segmental coordination to maximize impact power. These differences underscore the unique mechanical demands and performance outcomes associated with each punch.

The findings of this study emphasize the importance of tailored training programs that address the specific biomechanical characteristics of SP and HP. By refining these techniques, athletes can optimize performance while minimizing the risk of injury. Furthermore, integrating advanced methodologies, such as electromyographic analysis and multi-segment modeling, could provide deeper insights into muscle synergy and movement coordination, further enhancing training strategies in combat sports.

This research contributes valuable knowledge to the field of Sanda Wushu, offering practical applications for improving athletic performance and injury prevention. By bridging the gap between biomechanical theory and training practice, these findings pave the way for innovative approaches in high-level combat sports training.

Use of generative-AI tools declaration

The writers of this article affirm that they did not create it using artificial intelligence (AI) methods.

Acknowledgments

The authors are very grateful to the athletes and the members of the technical direction of the Tunisian Federation of Wushu Kung Fu, whose participation made this work possible.

Conflict of interest

No conflicts of interest are disclosed by the authors.

Author contributions

Conceptualization, S.E. and B.M.; methodology, S.E. and B.M.; software, B.M.; validation, B.M.; formal analysis, B.M.; investigation, S.E. and B.M.; resources, S.E. and B.M.; data curation, B.M.; writing original draft preparation, S.A.; writing—review and editing, B.M. and S.A.; visualization, S.E., and S.A.; supervision, B.M. and S.A.; project administration, B.M. All authors have read and agreed with the published version of the manuscript.

References

1. Turner AN, Baker E, Miller SC (2011) Increasing the impact force of the rear hand punch. *Strength Cond J* 33: 2−9. https://doi.org/10.1519/SSC.0b013e318232fdcb
2. Jiang C, Olson M, Li L (2013) Determination of biomechanical differences between elite and novice San Shou female athletes. *J Exerc Sci Fit* 11: 25–28. https://doi.org/10.1016/j.jesf.2013.03.002
3. Shouzheng F (2006) A biomechanical analysis of the Chinese wushu sanda side-kick as performed by elite male Wushu Sanda Competitors. Salzburg: Austria, 11−15.
4. Siddhartha S, Krishnendu D (2018) Selected kinematic analysis of side kick technique of elite wushu player. *J Phy Edu Res* 5: 53−57.
5. Ye DM, Qian BX (2003) Wushu Sanda Side kick structural and technical characteristics. *J PLA Inst Phys Educ* 22: 43−46.
6. Moussay S, Biomécanique et optimisation de la performance sportive. Paris: Fondation Sport Santé; 7ème colloque national, 75−80, 2007. Available from: https://www.tri-cote-damour.fr/site2016/images/stories/2010-2011/documents/biomcanique%20cycliste.pdf.
7. Shoukat H, Rabail A, Mirza M, et al. (2020) Comparing two types of punches (jab and cross) on the basis of maximum impact and muscle involvement. 2020 International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 1−5, https://doi.org/10.1109/ICEET48479.2020.9048191
8. Stanley E, Thomson E, Smith G, et al. (2018) An analysis of the three-dimensional kinetics and kinematics of maximal effort punches among amateur boxers. *Int J Perform Anal Sport* 18: 835−854. https://doi.org/10.1080/24748668.2018.1525651
9. Mosler D, Kacprzak J, Wąsik J (2024) The influence of effective mass on the striking force of lead jab and rear cross punches of boxers. *Appl Sci* 14: 7785. https://doi.org/10.3390/app14177785
10. Irina B, Dan D (2014) Kinematic analysis of the cross punch applied in the full-contact system using inertial navigation technology and surface electromyography. *Procedia Soc Behav Sci* 117: 335−340. https://doi.org/10.1016/j.sbspro.2014.02.223
11. Baitel I, Deliu D (2013) Kinematic aspects of direct punch cross and jab applied in semi-contact. 3: 97−101. https://doi.org/10.12753/2066-026X-13-230
12. Buśko K, Nikolaidis PT (2018) Biomechanical characteristics of Taekwondo athletes: kicks and punches vs. laboratory tests. *Biomed Hum Kinet* 10: 81−88. https://doi.org/10.1515/bhk-2018-0013

13. Wąsik J, Nowak K (2015) Influence of different versions of the straight forward punch on the obtained force, energy and power–measurements of taekwon-do ITF athletes' performance. 1st World Congress on Health and Martial Arts in Interdisciplinary Approach, HMA 2015, Czestochowa, Poland, 149–154.
14. Echeverria J, Santos OC (2021) Punch anticipation in a karate combat with computer vision; Adjunct proceedings of the 29th ACM conference on user modeling, adaptation and personalization, Utrecht, Netherlands, 61−67. https://doi.org/10.1145/3450614.3461688
15. Tong-Iam R, Rachanavy P, Lawsirirat C (2017) Kinematic and kinetic analysis of throwing a straight punch: the role of trunk rotation in delivering a powerful straight punch. *J Phys Educ Sport* 17: 2538−2543. https://doi.org/10.7752/jpes.2017.04287
16. International Wushu Federation I (2017) Wushu Sanda competition rules & judging method. IWF. Available from: http://www.iwuf.org/wp-content/uploads/2018/12/IWUF-Wushu-Sanda-Competition-Rules-Judging-Method-2017.pdf
17. Ouddak M (2015) Paramètres de développement de la coordination motrice pour une amélioration de la motricité et de la psychomotricité des jeunes sportifs. *MAAREF* 10: 03−29.
18. Piorkowski BA, Lees A, Barton GJ (2011) Single maximal versus combination punch kinematics. *Sports Biomech* 10: 1−11. https://doi.org/10.1080/14763141.2010.547590
19. Liu Y, Li L, Yan X, et al. (2023) Biomechanics of the lead straight punch and related indexes between sanda fighters and boxers from the perspective of cross-border talent transfer. *Front Physiol* 13: 1099682. https://doi.org/10.3389/fphys.2022.1099682
20. Mkaouer B, Akkari-Ghazouani H, Amara S, et al. (2023) Kinetic and kinematic analysis of landing during standing back somersault using three technical arm swings in artistic gymnastics. *J Funct Morphol Kinesiol* 8: 10. https://www.mdpi.com/2411-5142/8/1/10
21. Mkaouer B, Jemni M, Amara S, et al. (2014) Effect of three technical arms swings on the elevation of the center of mass during a standing back somersault. *J Hum Kinet* 40: 37−48. https://doi.org/10.2478/hukin-2014-0005
22. Brønd J (2009) *Biomechanics Made Simple*. SkillSpector: Video4Coach., 57.
23. Brønd JC, Elbæk L (2013) Problem based learning and the use of digital tools, for improving use and understanding of biomechanics in practical sports subjects. Proceedings of the 2nd NORDPLUS-IDROTT Conference. Odense, Denmark: University of Southern Denmark, 24.
24. Sharifnezhad A, Abdollahzadekan M, Shafieian M, et al. (2021) C3D data based on 2-dimensional images from video camera. *Ann Biomed Sci Eng* 5: 001−005. https://doi.org/10.29328/journal.abse.1001010
25. Harnois JS, Lavoie J (2017) De la biomécanique à la force de frappe. 43e Expo-Sciences au Cégep de Saint-Félicien. St-Félicien Canada, 5.
26. Hopkins WG, Marshall SW, Batterham AM, et al. (2009) Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3−13. https://doi.org/10.1249/MSS.0b013e31818cb278
27. Scanlan AT, Dascombe BJ, Reaburn P, et al. (2012) The physiological and activity demands experienced by Australian female basketball players during competition. *J Sci Med Sport* 15: 341−347. https://doi.org/10.1016/j.jsams.2011.12.008
28. Hopkins W, Marshall S, Batterham A, et al. (2009) Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3−13. https://doi.org/10.1249/MSS.0b013e31818cb278

29. Hopkins W (2000) Measures of reliability in sports medicine and science. *Sports Med* 30: 1−15. https://doi.org/10.2165/00007256-200030010-00001
30. Wagner JM, Rhodes JA, Patten C (2008) Reproducibility and minimal detectable change of three-dimensional kinematic analysis of reaching tasks in people with hemiparesis after stroke. *Phys Ther* 88: 652−663. https://doi.org/10.2522/ptj.20070255
31. Xu Q, Mao R, Xi C (2024) A comparative analysis of punching in boxing and sanda: kinematic differences based on the cross and uppercut. *Front Sports Act Living* 6: 1441470. https://doi.org/10.3389/fspor.2024.1441470
32. VencesBrito A, Rodrigues-Ferreira M, Cortes N, et al. (2011) Kinematic and electromyographic analyses of a karate punch. *J Electromyogr Kinesiol* 21: 1023−1029. https://doi.org/10.1016/j.jelekin.2011.09.007
33. Filimonov VI, Koptsev KN, Husyanov ZM, et al. (1985) Boxing: Means of increasing strength of the punch. *Strength Cond J* 7: 65−66. https://journals.lww.com/nsca-scj/fulltext/1985/12000/boxing__means_of_increasing_strength_of_the_punch.16.aspx
34. Beránek V, Votápek P, Štastný P (2020) Force and velocity of impact during upper limb strikes in combat sports: a systematic review and meta-analysis. *Sports Biomech* 22: 921−939. https://doi.org/10.1080/14763141.2020.1778075
35. Gulledge J, Dapena J (2008) A comparison of the reverse and power punches in oriental martial arts. *J Sports Sci* 26: 189−196. https://doi.org/10.1080/02640410701429816
36. Dinu D, Louis J (2020) Biomechanical analysis of the cross, hook, and uppercut in junior vs. elite boxers: implications for training and talent identification. *Front Sports Act Living* 26: 1−10. https://doi.org/10.3389/fspor.2020.598861
37. Dinu D, Millot B, Slawinski J, et al. (2020) An examination of the biomechanics of the cross, hook and uppercut between two elite boxing groups. *Proceedings* 49: 61. https://doi.org/10.3390/proceedings2020049061
38. Falco C, Alvarez O, Castillo I, et al. (2009) Influence of the distance in a roundhouse kick's execution time and impact force in Taekwondo. *J Biomech* 42: 242−248. https://doi.org/10.1016/j.jbiomech.2008.10.041
39. Mosler D, Kacprzak J, Wąsik J (2024) Higher values of force and acceleration in rear coss than lead jab: differences in technique execution by boxers. *Appl Sci* 14: 2830. https://doi.org/10.3390/app14072830
40. Bingül BM, Bulgan Ç, Tore O, et al. (2017) The effects of impact forces and kinematics of two different stance at straight punch techniques in boxing. *Arch Budo Sci Martial Arts* 13: 35−39. https://smaes.archbudo.com/view/abstract/id/11758
41. Smith M, Dyson RJ, Hale T, et al. (2000) Development of a boxing dynamometer and its punch force discrimination efficacy. *J Sports Sci* 18: 445−450. https://doi.org/10.1080/02640410050074377
42. Abazari R, Rostami M (2017) Segment-interaction analysis of a Kung-Fu straight punch. 24th National and 2nd International Iranian Conference on Biomedical Engineering (ICBME). Tehran, Iran, 1−5. https://doi.org/10.1109/ICBME.2017.8430235
43. Wąsik J, Góra T, Ortenburger D, et al. (2019) Kinematic quantification of straight-punch techniques using the preferred and non-preferred fist in taekwon-do. *Biomed Hum Kinet* 11: 115−120. https://doi.org/10.2478/bhk-2019-0016

44. Rinaldi M, Nasr Y, Atef G, et al. (2018) Biomechanical characterization of the Junzuki karate punch: indexes of performance. *Eur J Sport Sci* 18: 796−805. https://doi.org/10.1080/17461391.2018.1455899