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Research Article

The Measurement Method of the Impact Force of Shoulder Tackle and the Influence of the Lower-Extremity Strength on the Impact Force of Shoulder Tackle in Rugby Players

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With the rapid development of Internet of things engineering, intelligent sports products are gradually understood by people, providing help for the health and performance of athletes. In rugby training, coaches record and observe the force of data only based on their own experience; the impact force (IF) of shoulder tackle (ST) is a key defensive ability evaluation component for rugby players. However, the information related to female rugby players is limited. *Purpose*. To understand the strength characteristics of the lower-extremity of rugby players and to develop theoretical references for ST training. *Methods*. The force sensing device is made with FLexiForceTMA502 pressure sensor, its data acquisition adopts LabVIEW and USB. The strength of the lower extremity was tested by IsoMed 2000, and the IF of ST was measured by a testing system among eighteen Chinese female rugby players, respectively. *Results*. (1) The reliability and validity of the impact force tester are tested by comparing the actual load with the calibration value and the difference and correlation between the actual load value of different loads and the calibration value of it. (2) At 60°/s and 180°/s, the PT (PT) and relative PT (PT/BW) of bilateral lower-extremity extensors were greater than the flexors. (3) The flexor/extensor PT ratio of the left knee at 60°/s was higher than the right knee. (4) The linear regression equation was established between PT of dominant-side knee extensors and IF of ST. The coefficient β of the linear regression equation was 0.866, 0.862, 0.892, 0.722, 0.788, and 0.737, respectively. *Conclusions*. (1) The design uses LabVIEW, USB, and FLexiForceTM A502 pressure sensor to complete the overall construction of the data acquisition system and impact force sensing device. (2) It is feasible to use the extensor strength of the dominant-side knee joint as a reference index to evaluate the IF of ST. (3) The balanced development of the front/reverse ST techniques can enhance its defensive capacity of it.

1. Introduction

At present, the analysis of sports performance and training effects was carried out manually or with the help of software and applications. By applying the Internet of Things engineering in sports, the effect of athletes' training was analyzed with the help of sensors in wearable devices. In 2004, Australian Catapult launched the first GPS-5 Hz wearable exercise training monitoring device, which makes sports training and wearable devices deeply integrated, and sports training monitoring has entered the digital "black vest" generation [1]. In 2019, the clear-Sky sports performance intelligent evaluation system, which uses ultraoptical frequency data connection technology and gets rid of the limitation of GPS usage environment, and wearable devices in sports training entered an unprecedented era of rapid development [2].

Tracking athletes' health and performance through sensors and collecting movement data for analysis in the direction of an intelligent development in modern sports. It shows that the current technical shortcoming of the Chinese women's national team was the defensive ability of ST [3]. In order to change the impoverished and enfeebled situation of rugby sports in China, the assistance of science and technology, as well as the cross-boundary and cross-type selection of athletes, will also accelerate the expansion of rugby sports.

ST is a basic defensive action that would occur more than 200 times per game [4]. There were many research studies on the influence of lower-extremity strength on the ST technique. Speranza et al. found that the ST technique of players was correlated with the lower-extremity maximal and explosive strength [5]. On the other hand, Jenkins and Gabbett measured the influence factors of the ST technique and found that lower-limb strength was one of the factors affecting the impact force of shoulder tackle in the multiple regression model [6].

The lower-extremity strength had different defensive effects on ST of distinct body positions and was correlated with the game results [7]. To be specific, ST was primarily affected by the technical actions and lower-extremity strength [8]. ST is highly correlated with the squat strength [5]. Moreover, the correlation between ST ability and the vertical squat jump performance was tight. The squat performance was also related to the PT, the relative PT, and the flexor/extensor ratio of lower-extremity joints [9].

The high impact and physical nature of the tackle during a rugby match place the tackler(s) and ball-carrier at risk of injury, and such injuries account for up to 61% that occur during a rugby match [10]. The collision tackle tends to elicit a large number of impact forces due to rapid acceleration before a collision followed by high impact forces, transferring momentum between opposing players. Partly due to such extreme mechanical variables, the most frequent cause of injury is the direct impact of tackling, which is tackling technique drills and conditioning exercises [11,12].

The balance of ST was stabilized by the joint structure and muscle strength of the lower extremities. Comfort et al., at a fixed angular velocity of 60°, tested the PTs and torque ratios of hamstrings and quadriceps during concentric and eccentric movements of the knee joint. The hamstring/quadriceps ratios were identical between the dominant and nondominant legs, as well as forwards and backs. In addition, the flexor/extensor PT ratios were correlated to sports injuries [8]. In 2016, Brown showed that the hip and knee PT and the flexor/extensor PT ratios were different between the two legs of college rugby players. To be specific, the flexor/extensor PT ratios in college players were lower than the ratios in professional athletes, and the hip and knee PT of the forwards were greater than the backs [13]. The 2014 research of Brown et al. found that the rugby league and rugby union players had different hip and knee strength, where the hip extensors of rugby union players and the knee flexors of rugby league players were weaker. This imbalance would influence the performance of rugby players in sprinting, changing direction, and kicking [14]. The research by Dobbs et al. indicated that the ratios of the nondominant legs were greater than the dominant legs and encouraged to use the flexor/extensor PT ratio of the knee joint as an indicator to assess the preseason competitive state of the players and to predict the potential of sports injuries [15].

However, the research on the relation between the technical and tactical of rugby and the biomechanical characteristics of the female rugby players is insufficient. In particular, the evidence for the correlation between the defensive ability of ST and the lower-extremity strength needs further studies. In this paper, the IF of ST was tested by the testing system which consisted of hardware and software parts. The hardware part mainly included a force sensor, data acquisition card, and computer to collect, convert, transmit, store, and display. The software part involved an application program to implement the design and control of the data acquisition program, as well as a hardware driver to complete the working mode setting of the data acquisition card. We performed objective measurements and characteristic analysis on Chinese elite female rugby players' isokinetic hip, knee, and ankle strength. Meanwhile, the impacts of lower-extremity strength on ST techniques are explored, providing a theoretical reference for the specialized strength training, the technical learning and the injury prevention of rugby players, and the evidence of relevant research studies on rugby in the process.

Table 1: Participant characteristics.

Total ($N = 18$)	Age (y)	Height (cm)	Mass (kg)	Dominant shoulder
Eigenvalue	19.7 ± 3.1	168.4 ± 3.5	62.9 ± 5.3	R16/L2

2. Materials and Methods

2.1. Participants. Eighteen voluntary players without any injury within three months or having more than three-month training after recovery (based on the time recorded in the medical rehabilitation certificate) participated. The test duration was one week, and corresponding adjustments and arrangements were made for special situations. The basic characteristics of the subjects are shown in Table 1.

2.2. Methods. The idea of a shoulder tackle impact force tester is as follows. (1) According to the characteristics of the shape (length and width of the shoulder) and the impact force of the shoulder of women rugby players, the FLex-iForceTMA502 piezoresistive pressure sensor is selected to make the impact force-sensing device-pressure test vest. Three sensor pieces are placed in parallel at the position of the shoulder guard to sense the impact force. (2) The impact force data acquisition system is designed by using the LabVIEW data acquisition program and USB multichannel data acquisition card. (3) The scientificity and practicability of the force tester had been tested through practical application, as shown in Figure 1.

2.2.1. Working Principle of Pressure Sensor. The force of the impact was tested by the piezoresistive pressure sensor in research, which was based on silicon wafers as an elastic sensitive element; the four equivalent conductor resistances and the Wheatstone bridge were made of the diaphragm diffusion process with an integrated circuit; when the diaphragm is stressed, due to the semiconductor piezoresistive

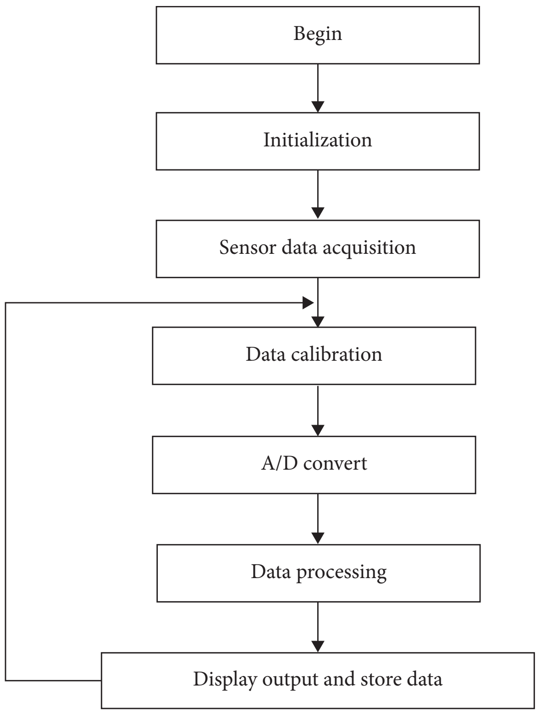

FIGURE 1: The data acquisition process of shoulder tackle impact force tester.

effect, the resistance value changes, so that the bridge output measured the change of pressure, using this method to make pressure sensor, as shown in Figure 2.

The piezoresistive pressure sensor, mainly using the resistivity $\Delta\rho/\rho$, changes, and the result of the piezoresistive effect is as follows:

$$\frac{\Delta R}{R} = (1 + 2\mu)\zeta + \pi_L E\zeta = K_S\zeta, \quad \pi_L E\zeta = \frac{\Delta\rho}{\rho}. \tag{1}$$

2.2.2. USB Multichannel Data Acquisition Card. The USB multichannel data acquisition card is run on the LabVIEW general acquisition platform of the Windows operating system and powered by a computer. USB multichannel data acquisition card is mainly composed of an isolation circuit, A/D conversion circuit, digital quantity input circuit, a digital quantity output circuit, isolation communication interface, and MCU. The microcontroller adopts a 16-bit ARM chip with strong data processing capacity and watchdog circuit, which can restart the system in case of accidents, making the system more stable and reliable, and can be applied in high performance and high-speed application environments. Photoelectric isolation is adopted between the input and output units and the control unit, and filtering measures are taken for the input signal, which greatly reduces the influence of field interference on the operation of the acquisition card and makes the module have high reliability. The data acquisition system in this study adopts USB2.0 multichannel data acquisition card with 10 terminals, as shown in Figure 3. See Figure 4.

2.2.3. The Impact Force of Shoulder Tackle Testing, as Shown in Figure 4

2.2.4. Setting of Range of Force Sensing Device. The kinematic index of shoulder tackle was measured in the laboratory, and the maximum impact force was predicted. The experimental subject was 55 kg Chinese women's rugby players. Experimental kinematic data were filtered by a Butterworth second-order bidirectional low-pass filter with a cutoff frequency of 10 Hz. The Vicon system was used to make up points and intercept the complete shoulder movement; then, the C3D file was exported and imported into Visual 3DTM (USA C-Motion, Version: 4.00.20) for kinematic data processing. We use the Visual 3DTM software for static modeling of kinematics data, import athlete static calibration C3D file in Visual 3D, personalized modification of athlete's height, body mass, then build a static model mdh file set for dynamic data C3D file, and establish dynamic model. After the model is applied, the kinematic data is calculated by using the Pipeline data processing program built in Visual 3D. The direction of the impact force is the flexion and extension movement of the sagittal plane of the body (defined as the motion of the Z and Y axes). After the impact, the feet leave the ground, and the change of velocity ΔV in the sagittal plane of the Y and Z axes is derived from the momentum theorem formula:

$$F = \left(\Delta VM - \cos\ \cdot \theta \cdot G. \cdot \Delta \cdot t_0\right)\%\Delta \cdot t_0. \tag{2}$$

The theoretical maximum value of shoulder tackle impact force can be obtained through kinematic data:

$$\begin{aligned} F\Delta t &= \sqrt{V_Y^2 + V_Z^2}M - \cos\theta G\Delta t, \\ F &= \frac{\sqrt{1.084^2 + 0.248^2}}{0.035} \times 55 - \cos 30^\circ \times 55 \times 9.8. \end{aligned} \tag{3}$$

It is 1280 N about 230% of the body weight. Combined with existing studies, the impact force of the shoulder tackle on lite male athletes is 175% and 223% of their body weight in running and jumping and 128%–157% of their body weight in walking. The maximum impact force of shoulder tackle is 1274 N (130 kg), which is used as the reference and basis for designing the range of impact force sensing devices.

In this paper, the piezoresistive pressure sensor is used to sense the impact force, so as to make a pressure sensor. The piezoresistive pressure sensor is based on silicon wafers as an elastic sensitive element, and four equivalent conductor resistances are made of an integrated circuit diffusion process on the diaphragm, forming the Wheatstone bridge. When the diaphragm is stressed, as a result of the semiconductor piezoresistive effect, leading to resistance change, the change in pressure is measured by making the bridge output, using this method that made the pressure sensor.

It is mainly used for the change of resistivity $\Delta\rho/\rho$ and the piezoresistive effect. Piezoresistive pressure sensor is as follows:

$$\begin{aligned} &\Delta \cdot \frac{R}{R} = \cdot (1 + 2\mu) \cdot \zeta + \pi LE\zeta \cdot = \cdot KS\zeta, \\ &\pi LE\zeta \cdot = \cdot \Delta\frac{\rho}{\rho}. \end{aligned} \tag{4}$$

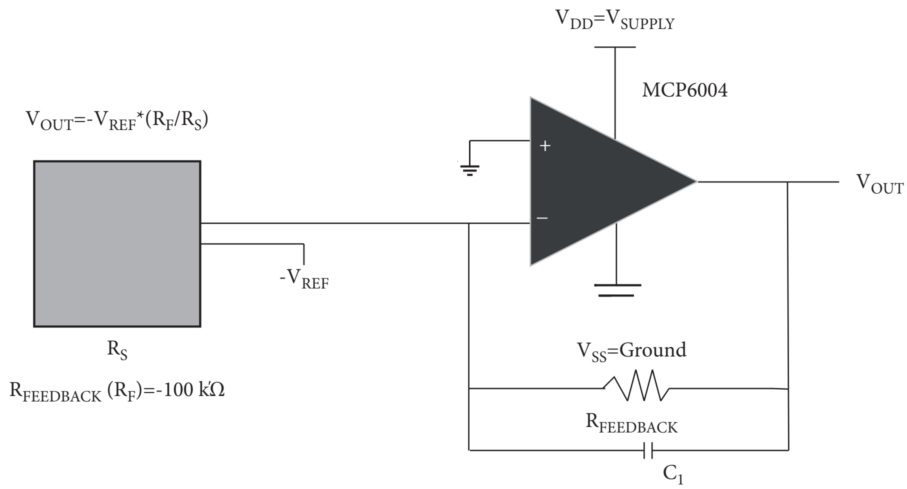

Figure 2: A method for expanding the range of the sensor.

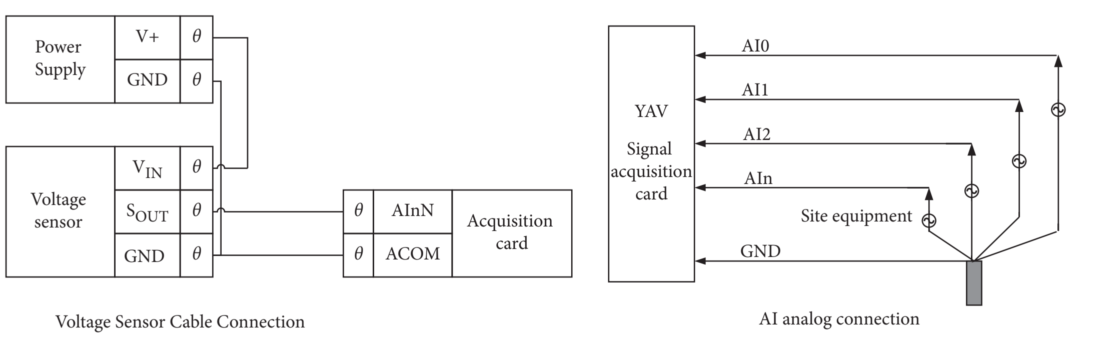

Figure 3: Sensor wiring and AI analog quantity wiring. (a) Voltage sensor cable connection. (b) AI analog connection.

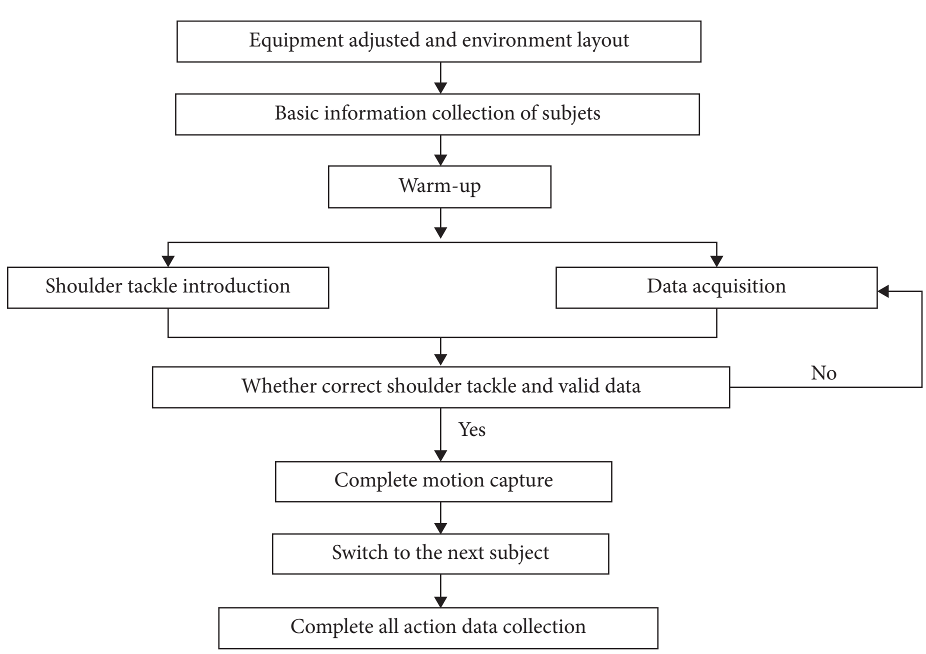

Figure 4: Flow chart of shoulder impact force test.

2.3. Experimental Design. The isokinetic strength testing instrument was an IsoMed 2000 (F&D, Germany), and the manufacturer´s computer software IsoMed analyze V.3.1 was used. The testing contents included PT, relative PT, average power, relative average power, and the flexor/extensor PT ratio of the bilateral hip, knee, and ankle joints.

There was a unified arrangement of tests, the specific time was arranged in the middle of the training, and the test was completed within a week. Participants were given appropriate rest between trials (>2 min) to prevent the effects of fatigue.

The testing scheme includes the flexion/extension actions of the hip, knee, and ankle joints. In the preparation phase, the test requirements and cautions were explained to the athletes, and a fifteen-minute warm-up was taken, including ten-minute slow treadmill running where the treadmill machine was ICON SFTL27808 ad treadmill running speed was 9 km/h, and a five-minute dynamic stretching. Furthermore, the athletes were given at least three familiarization trials at each joint and each speed until they performed the movement properly. Since the angular velocity of the ankle-joint sagittal movement in ST action was less than 180°/s (the results of the experimental testing on the Ph.D. project), combined with existing relevant research studies [16], 60°/s and 180°/s were selected as the fixed angular velocities for the testing. In formal testing, each joint was tested at 60°/s and 180°/s through concentric actions during seated knee-extension/flexion and supine hip (ankle)-extension/flexion actions. At each velocity, 5 flexion and 5 extension actions were tested, and two to four test results were taken. The rest between the tests of contralateral homonymous joints was three minutes, and forty-minute intervals were required for heteronymous joints. The methodology was strictly implemented by professional operators in accordance with the operating instructions, and the testing reports were printed automatically by the system. Moreover, the average of the four repetitions was used as the final value, with the parameters of the isokinetic strength test.

The impact force of ST was tested by the self-developed testing system (Invention Patent Number: ZL201910594285.9), which consisted of hardware and software parts. The hardware part mainly included a force sensor, data acquisition card, and computer to collect, convert, transmit, store, and display. The software part involved an application program to implement the design and control of the data acquisition program, as well as the hardware driver to complete the working mode setting of the data acquisition card, as shown in Figure 5.

2.4. Statistical Analysis. A parametric test was performed in SPSS (Version 25.0 for Windows, SPSS Inc., Chicago, IL, USA), and one-sample K–S test was used to measure whether the data of the lower-extremity isokinetic strength and the impact force of ST followed the normal distribution.

The statistical data of the impact force of ST and the isokinetic strength were expressed as mean ± SD and were examined through an independent-sample *t*-test, which considered $P < 0.05$ to be statistically significant and $P < 0.01$ to be extremely significant, tested through Pearson correlation, and linear regression analysis between impact strength of ST and isokinetic strength of the low-extremity joint movement.

3. Results

3.1. The Reliability and Validity of the Impact Force Tester Was Tested by Comparing the Actual Load with the Calibrated Value. There is no significant difference between the external load and the scalar value of the tester ($P \leq 0.001$), and the two values have a highly positive correlation (Pearson correlation coefficient is "1"), which fully shows that the tester has reliable performance and high reliability; the detailed results are shown in Tables 2 and 3.

The reliability and validity of the impact force tester were tested by using the difference and correlation between the actual load values of different loads and the calibrated values of the tester.

3.2. PT and Relative PT. The PT and PT/BW of the ipsilateral extensors were significantly higher than the flexors, and their differences were extremely significant ($P < 0.01$) where the hip, knee, and ankle joints of the lower extremities moved at 60°/s and 180°/s [15]; the detailed results are shown in Tables 4 and 5.

3.3. Average Power and Relative Average Power. With the hip, knee, and ankle joints moving at fixed angular velocities of 60°/s and 180°/s, the relative average power of the ipsilateral extensors was significantly larger than the flexors, and there were significant differences between these muscles. At an angular velocity of 180°/s, the average power and the relative average power of the contralateral homonymous knee muscles had an extremely significant difference ($P < 0.01$). The detailed results can be seen in the corresponding statistics in Figures 6 and 7.

3.4. Flexor/Extensor PT Ratio. When the knee joint of the lower limbs moved at a fixed angular velocity of 60°/s, the flexor/extensor PT ratios were significantly different between the left and right knees, and the ratios of the right knee were higher than the left knee. The detailed results are shown in Figure 8.

3.5. Correlation between Lower-Extremity Isokinetic Strength and IF of ST. The results as shown in Table 6 showed the impact force of ST.

According to the analysis of statistical data, the correlation between the relative PT of the right knee extensors and the low/middle position of front ST had a significant

Figure 5: Application of impact force testing system.

Table 2: Comparison of external load value and tester calibrated value.

external Load (N)		588	588	637	686	725	784	833	882	931	980	1029	1078	1176	1225	1274
	First time	480	576	625	673	711	779	816	866	912	962	1010	1068	1154	1220	1268
Calibrate	Second time	481	575	625	672	711	778	815	869	912	960	1010	1069	1156	1220	1268
	Third time	482	576	626	672	711	779	814	867	912	961	1010	1070	1156	1219	1264

Table 3: Pearson correlation between external load value and calibrated load value of the impact force tester, and measurement standard error (SEM), 95% confidence interval difference, and percentage difference.

load Value	SEM	Confidence interval (95%)		Pearson correlation	P	Difference
		Minimum	Maximum	Coefficient (R)		Value%
First time	5.244	10.472	16.528	1	≤0.001	<5%
Second time	5.484	9.905	16.238	1	≤0.001	<5%
Third time	5.650	9.667	16.191	1	≤0.001	<5%

Table 4: Descriptive statistics for isokinetic PT (nm) of the lower extremities.

	60°/s angular velocity		180°/s angular velocity	
	Flexion	Extension	Flexion	Extension
Left hip	123.2 ± 4.2	228.3 ± 12.3	101.2 ± 8.1	168.31 ± 15
Right hip	$126.6 \pm 4^{**}$	$234.7 \pm 4.5^{**}$	$103.4 \pm 8.3^{**}$	$174 \pm 15.2^{**}$
Left knee	111.8 ± 5.5	182.9 ± 4	89.9 ± 2.8	126.4 ± 3.9
Right knee	$105.4 \pm 4.5^{**}$	$199.2 \pm 7.8^{**}$	$86.7 \pm 4.4^{**}$	$134.4 \pm 4.1^{**}$
Left ankle	23.7 ± 1.5	100.1 ± 5.3	18.34 ± 2.9	63.6 ± 3.2
Right ankle	$26.3 \pm 1.7^{**}$	$110.6 \pm 7.1^{**}$	$19.9 \pm 2.6^{**}$	$60.9 \pm 4.4^{**}$

$**$Significantly different between flexion and extension $P < 0.01$.

correlation in the 99% confidence interval; PT and high position of front ST, high position of reverse ST, and middle position of reverse ST were significant in the 95% confidence interval [17], as shown in Table 7.

There was a linear regression between the PT at 60°/s extensors of the right knee and IF of ST in different positions. The results showed a significant variance $P < 0.05$, and the regression results were statistically significant, as shown in Table 8.

4. Discussion

4.1. Isokinetic Hip Strength Analysis. The muscles at the hip joint are the strongest part of the lower extremity, which provide strength in the process of stretching in ST. This body can obtain a certain velocity in the front and upper directions to promote the stretching of the knee and ankle joints [18].

During the movements of the hip joint at fixed angular velocities of 60°/s and 180°/s, the differences between the

Table 5: Descriptive statistics for isokinetic PT/BW of the lower extremities.

	60°/s angular velocity		180°/s angular velocity	
	Flexion	Extension	Flexion	Extension
Left hip	2.04 ± 0.07	3.593 ± 0.2	1.84 ± 0.14	2.59 ± 0.25
Right hip	2.05 ± 0.06**	3.73 ± 0.07**	1.85 ± 0.15**	2.76 ± 0.26**
Left knee	1.87 ± 0.1	1.67 ± 0.07	1.42 ± 0.04	2.01 ± 0.06
Right knee	2.91 ± 0.08**	3.15 ± 0.13**	1.38 ± 0.08**	2.16 ± 0.07**
Left ankle	0.38 ± 0.02	1.58 ± 0.09	0.29 ± 0.04	1.01 ± 0.05
Right ankle	0.42 ± 0.03**	1.76 ± 0.1**	0.32 ± 0.03**	0.97 ± 0.07**

**Significantly different between flexion and extension, $P < 0.01$.

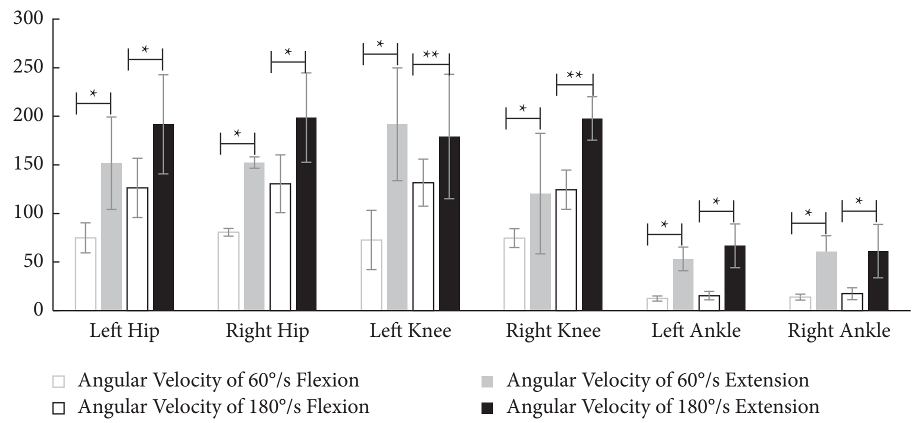

Figure 6: Descriptive statistics for average power (J) of the lower extremities. *Significantly different between the left side and right side, $P < 0.05$. **Significantly different between flexion and extension, $P < 0.01$.

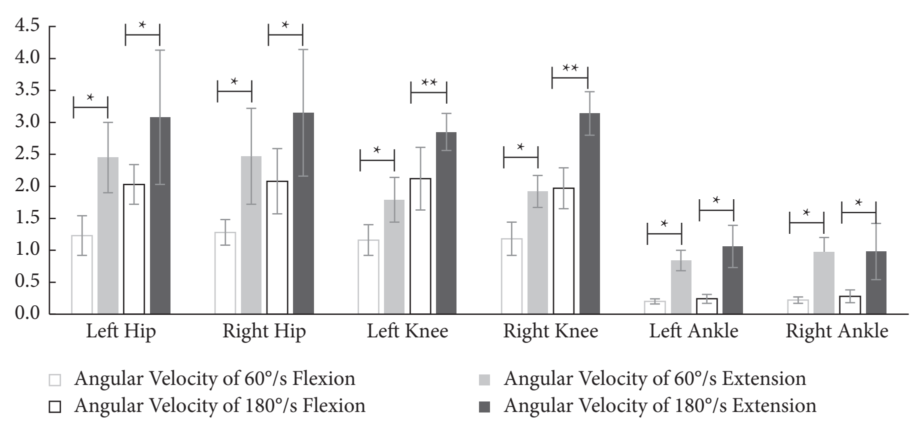

Figure 7: Descriptive statistics for the relative average power of the lower extremities. *Significantly different between the left side and right side, $P < 0.05$. **Significantly different between flexion and extension, $P < 0.01$.

contralateral homonymous flexors and extensors were within 10%, which indicated that the movements of hip flexors and extensors were in a normal and safe range. The distinction between the ipsilateral hip flexors and extensors could be partly explained as an adaptation to rugby sports. Mauling and the formation and propulsion of scrummaging, as well as tackling, which is the most commonly used defensive action, are mainly comprised of hip flexion and extension movements in the sagittal plane. Generally, catching and pick-and-goes begin from an upright position, and the sprint usually starts from change-of-direction movements. Most importantly, the rugby players generally stand upright for ST defense in training and matches; thus, the hip extension in the sagittal plane is the major action [19].

The hip and relative PT of the flexors and extensors at the angular velocity of 180°/s were obviously lower than 60°/s, which was consistent with many relevant studies [12, 14]. The main reason is that the excitement and tension of the muscle fibers will take time to generate, which indicates that the faster movement speed will reduce the muscle contraction time and the number of muscle fibers collected,

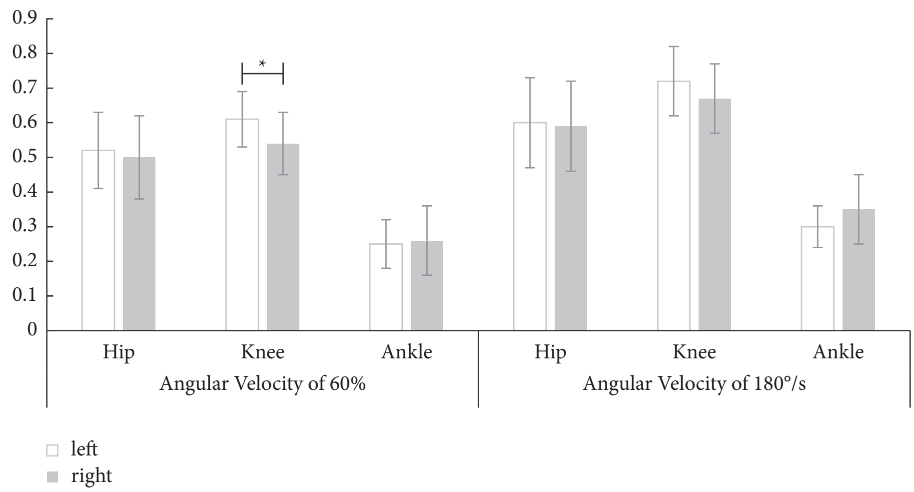

Figure 8: Descriptive statistics for the flexor/extensor PT ratio of the lower extremity. ∗ Significantly different between flexion and extension, $P < 0.05$.

Table 6: IF of front and reverse ST in different positions.

$N = 18$	Front ST			Reverse ST		
Position	High	Middle	Low	High	Middle	Low
IF(N/BW)	1.06 ± 0.09	1.19 ± 0.06	1.18 ± 0.07	1.00 ± 0.14	1.15 ± 0.08	1.10 ± 0.11

Table 7: Pearson correlation between relative PT of right keen extensors and IF of ST.

Angular velocity: 60°/s	Relative PT of right knee extensors (R)
IF of front ST in a high position	0.654*
IF of front ST in a middle position	0.670**
IF of front ST in a low position	0.691**
IF of reverse ST in a high position	0.554*
IF of reverse ST in a middle position	0.574*
IF of reverse ST in a low position	0.460

*Significantly correlated in the 95% confidence interval (two-tailed test).** Significantly correlated in the 99% confidence interval (two-tailed test).

Table 8: Results of linear regression analysis.

Angular velocity: 60°/s ($p < 0.05$)	PT of extensors of the right knee	
	β	Model equation
IF of front ST in a high position	0.866	$Y = 0.866x$
IF of front ST in a middle position	0.862	$Y = 0.862x$
IF of front ST in a low position	0.892	$Y = 0.892x$
IF of reverse ST in a high position	0.722	$Y = 0.722x$
IF of reverse ST in a middle position	0.788	$Y = 0.788x$
IF of reverse ST in a low position	0.737	$Y = 0.737x$

Note. The independent variable is the PT of the right knee extensor muscle, the dependent variable is IF of ST, and β is the standardized regression coefficient.

resulting in a decrease in the strength generated. When the slow movement is at 60°/s, slow-twitch muscle fibers are primarily collected and a certain proportion of oxidative energy supply is contained. It is worth mentioning that the fast movement at 180°/s will trigger the collection of fast-twitch muscle fibers. Moreover, the intensity of rugby sports is between high and extreme, while the mode of energy supply is dominated by anaerobic metabolism [20]. In general, the low-speed hip strength training of the athletes is satisfactory; nevertheless, the speed strength should be enhanced.

Note that the female rugby players in the current study had the flexor/extensor ratios of 0.54–0.7 at 60°/s and 180°/s, respectively, while male football players (0.7–0.9) at 50°/s and 200°/s are less [21]. Scott R. Brown's studies indicated there was a great difference between dominant and non-dominant legs isokinetic strength testing at 60°/s of rugby male players; the difference may be partially explained by the technique demands of rugby: tackles made primarily to dominant legs, reception, and running with the ball generally from upright positions, and sprint efforts commonly preceded with backward running. The net effect is that players who do training and play in a more upright position use their dominant hip extensors as the main producers of force, work, and power [14]. Unfortunately, no profiling of rugby female players' hip strength has been reported. There is a need for strength profiling of elite players of the hip, as this helps understand the requirements and characteristics of rugby players, as well as guiding specific conditioning practices to better effect.

With the movements of the hip, knee, and ankle joints at fixed angular velocities of 60°/s and 180°/s, the average power and the relative average power of the flexors and extensors were different, which reflected that the maximal and explosive strengths of the extensors were higher than the flexors. At a fixed angular velocity of 180°/s, the average power and the relative average power of the flexors and extensors were improved, and the power increased with the rise of movement velocity is in a certain range. However, when the movement velocity of muscles reached the threshold, the power started to decrease with faster movement, and therefore, the average power was adopted as the standard.

At the same velocity, the average power and the relative average power of the extensors were higher than the flexors, indicating that the function of the extensors was superior to the flexors on the same condition. The reason was that the offense and defense of rugby sports were mainly based on stretching and supplemented by the buffer technique after touching land. The test results were constant with previous studies and reflected that the rugby players enhanced the ability to collect muscle fibers of the flexors at higher movement velocity. It was the requirement for rugby players to balance the development of the hip flexors and extensors and to adapt to this specialized sport.

Although the hip joint is not crucial in the close-range movements of rugby, it is a major joint of the lower-limb stretching and maintaining movement balance [22].

4.2. Isokinetic Knee Strength Analysis. At the beginning of ST, the hip joint drives the knee joint to stretch and to generate appropriate lengths of contraction for the extensors at the best exertion angle, making the knee extensors contract concentrically. The muscles of the knee joint make the greatest contribution to the impact force of ST. In international studies, the flexor and extensor strength of the knee joint are one of the focuses of lower-limb strength in rugby players. Most of the studies claimed that the reasonable hamstring-to-quadriceps ratio (H/Q ratio) affected the learning of sports techniques such as balancing and coordinating capacities and was correlated to sports injuries [12, 23, 24].

H/Q ratio calculated by dividing the peak flexion torque by the peak extension torque of the same knee is optimal between 60% and 65% [16, 25]. It is also a major indicator of knee joint injury rehabilitation when its range is between 0.5 and 0.8. A lower ratio could influence the stability of the knee joint and cause joint injury. For a higher ratio, the knee joint lacks stretching strength, which could affect the quality of running speed. The coordination of the passing and catching actions and the impact force of tackling and other specialized technical movements in rugby sports exist. The research results showed that the H/Q ratios in Chinese elite female rugby players were between 0.6 and 0.8, which were consistent with the international amateur female rugby players [15], as well as other excellent basketball and football players [26, 27]. The H/Q ratios of the dominant legs were much higher than the nondominant legs. Moreover, the knee extensors had relatively greater strength, which was the result of habitually using ST techniques in general rugby sports [7].

The phenomenon that the relative PT changes with rising movement velocity is because the break and formation of the cross-bridges in myofibers will lose muscle strength. Besides, the fluid viscosity of the myofibers and the connective tissues requires internal forces to overcome the viscous resistance, which will cause the decline of muscle tension. The contraction of the agonistic muscles and the extension of the antagonistic muscles could also cause the loss of muscle strength due to the viscosity of muscle, and the viscous resistance is increased with higher contraction speed.

The average PT of knee extensors in Chinese female rugby players was 199.21 ± 29.9 Nm, while the PT in international elite female handball athletes was 162.77 ± 26.54 Nm [28]. In addition, the average relative PT of the knee in Chinese female rugby players was 1.78 ± 0.32, compared to 1.7 ± 0.4 in international excellent female football players [21].

The flexor/extensor PT ratios between the dominant and nondominant leg in Chinese female rugby players were different at a fixed angular velocity of 60°/s. In addition, the average power and the relative average power between the extensors of the left and right leg were also different at 180°/s. The explosive strength to mobilize the muscles quickly and the maximal extensor strength of the dominant leg were stronger than the nondominant leg. The main reason is that the offense and defense of rugby sports are composed of multifrequency sudden stops and starts, as well as highly accelerated movements in changing directions. ST is the most frequently used tackling action in defense, accounting for 61% of the total tackling actions use [29]. In each game, the forwards of the team are exposed to an average of 55 physical collisions, while the backs are exposed to 29 physical collisions on average [18]. Most athletes habitually choose the right shoulder as the dominant shoulder and frequently perform ST actions using the dominant shoulder in training and matches, leading to the different muscle strength between the left side and right side of the knee joint.

In conclusion, the knee extensor strength in Chinese elite female rugby players was well developed, while the extensor strength between the left and right knee was imbalanced. It is recommended to focus on the balanced development of the lower-extremity left side and right side extensor and flexor strength in strength training, increasing the hamstring-to-quadriceps ratio of the knee joint, and enhancing the strength or stretching exercises of the hamstrings.

4.3. Isokinetic Ankle Strength Analysis. The ankle joint is the terminal joint and is the point of strength conversion. Through the transmission of the ankle joint, the hip and knee strength could be applied to the ground. Particularly in the stretching phase of sprinting, the ankle strength determines the stability of completing the supporting actions, as well as the functional efficiency of the upper joints and the time sequence of participating in the movement [30]. The ankle joint is also the most easily injured joint, accounting for 25% of the total injuries in running and jumping sports. In the latest research from Noronha, the injury rate of the ankle joint was 1.63 per 1000 competition hours based on the duration of rugby union games, and the rate was 0.063 per game based on the number of series [31]. The research of Sman reported that the injury rate of the ankle ligament in rugby union games was 0.89 per 1000 competition hours, and the rate in rugby league games was 0.46 per 1000 competition hours [32].

The relevant research results indicated that the average PT ratio of the dorsiflexors and the plantar flexors was between 0.26 and 0.35. In addition, other studies showed that when the lower-limb extensors were well developed, the flexors were correspondingly well developed. The PT of plantar flexor muscle groups in the ankle joint was about three times of the dorsiflexor muscle groups. The main reason is that plantar flexor muscle groups play a leading role in the contraction of the ankle muscle groups. Accordingly, the maintenance of standing posture and general activities in daily life require lots of participation in plantarflexor muscle groups, and the extensors usually have a heavy burden in normal sports.

The difference between the ankle flexor/extensor PT ratios in Chinese elite rugby players and the reasonable value was within a variation range of 10% to 15%, and the PT of plantar flexor muscle groups was about four times of the dorsiflexor muscle groups [14]. The latest studies found that the strength of the dorsiflexor muscle groups affected the balance capacity (Y). There was a linear relationship shown as $Y = 71.08–0.81 \times CS_{ML} + 5.47 \times PT_{HABD} + 0.24 \times ADF_{KF}$, where CS_{ML} was the displacement of the barycenter, PT_{HABD} was the maximal strength of the hip abductor, and ADF_{KF} was the ankle dorsiflexor muscle strength [22]. Therefore, the Chinese female rugby players should enhance the strength training of the ankle dorsiflexor muscle groups and evenly develop the flexor and extensor strength of the ankle joint.

4.4. Impact of Lower-Extremity Strength on ST. The lower-extremity movement of ST was the stretching in the asymmetrical and nonvertical jump. In the stretching stage, the extensors contracted concentrically to generate a torque, which indicated that the vertical and horizontal momentum is determined by the muscle strength, the body movement speed, and eventually the impact force [12]. The linear relationship between the extensors of the dominant knee and IF of ST indicates the motion characteristics of the characteristic of ST action, in which the extension knee provides strength in the pedal and stretches the process in ST, and the body can obtain a certain velocity in the front and upper direction. The testing strength of low-extremity evaluates the defensive ability of ST, and it could help the coach to reasonably arrange the tactics and the defensive position of the defenders.

The relative PT and the relative average power of lower-extremity isokinetic strength at fixed angular velocities of 60°/s and 180°/s reflected the maximal strength and power of flexors and extensors. The balanced development of the flexor and extensor strength improved the defensive effect of ST and maintained the balance and stability of ST. Isokinetic strength was correlated with IF of ST. The results of this research showed that IF of ST was positively correlated with the PT of the right knee and left ankle extensors. Furthermore, the impact effect of ST was correlated with the extensor strength of the front knee of the dominant side. These correlations conformed to the sports biomechanical characteristics of the ST leading to the result of ST technique adapting to the exertion features of the lower-extremity joints. Athletes were tended to defense with the right side for front ST, and therefore, the right knee extensors could be easily activated at a suitable angle. On one hand, through specialized strength training of knee extensors, IF of ST could be improved. On the other hand, the learning of unilateral (right side) ST technique could cause the imbalance between the lower-extremity strength; the specialized strength training was needed to balance development the strength of the flexors and extensors.

The main problem of the lower-extremity strength in Chinese elite female athletes is the fact that the extensor strength of the dominant knee is greater than the non-dominant knee. Particularly, the maximal strength of the flexors and extensors is severely imbalanced, where the extensor strength is four times the flexor strength. On the one hand, the superior strength of the dominant knee joint and the insufficient flexor strength of the left and right ankle joints prevent the full transmission of the hip and knee strength in ST action. They also reduce the buffer ability of the foot after touching land and ultimately affect the force and speed of ST action. On the other hand, the imbalance between the flexors and extensors of the knee and ankle joint could lead to the instability of ST action and influence the balance, stability, and technical learning of the action. Even worse, this problem could also cause joint injuries easily.

The effective measures to improve ST ability are firstly developing lower-extremity strength in a balanced manner, especially the flexors and extensors of the unilateral side. Next, the left and right side ST techniques need to be developed evenly. The novice athletes should adopt left or right ST based on different distances. The habitual adoption of dominant ST defense could cause the imbalance of strength between the left and right sides of lower-extremity strength. In a word, the reverse ST reduces the defense effect and easily causes injuries.

There is one key part of this study, the measuring instrument of ST impact force is designed according to the physiological characteristics of female athletes, and the force-sensing device can accurately measure the ST impact force of female athletes, which can help rugby coaches improve the effect of technical tackle training.

5. Conclusion

In this paper, the design uses the LabVIEW, USB multichannel data acquisition card, and FLexiForceTM A502 pressure sensor to complete the overall construction of the data acquisition system and impact force sensing device. Through the application, the accuracy, reliability, and practicability of the data processing function of the tester system are fully verified. The tester can easily and effectively measure the force of the woman's shoulder tackle, which has the promotion value.

A variety of sensors are applied to athletes' wearable devices to achieve intelligence. The lower extremity of unilateral extensors in Chinese elite female rugby players was greater than the flexors. Meanwhile, the imbalance between the bilateral knee extensors and flexors limits the improvement of the defensive ability of ST. It is feasible to use the extensor strength of the dominant-side knee joint as a reference index to evaluate the defensive ability of ST. The balanced development of the lower-extremity strength and the front/reverse ST techniques can help the athletes to enhance the stability of ST actions and the defensive capacity and to prevent injuries effectively. Based on the experiment verification in this paper, the force tester will be further verified and improved and popularized in sports, and the proposed network should be validated in the theoretical analysis and practical applications in future work.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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