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# Jumping Side Volley in Soccer – A Biomechanical Preliminary Study on the Flying Kick and Its Coaching Know-How for Practitioners

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**Abstract:** Jumping side volley has created breathtaking moments and cherished memories for us. Regrettably, a scientific study on the skill has not been found in literature. Relying on talent of athletes to improvise on the fly can hardly be considered a viable learning strategy. This study targets to fill the gap by quantifying factors contributing to develop its coaching method. Using 3D motion capture (12-cameras, 200Hz) and full-body biomechanical modeling, our study aimed to identify elements that govern entrainment of the skill by examining jumping, kicking and falling phases of its execution. Given the rarity of players who have acquired this skill, we found five subjects for the study. Twenty-three trials were captured and quantified. The results unveil the following key elements: 1) the control of trunk rotation during the jumping, 2) the angle between thighs upon take-off, 3) the whip-like control of the kicking leg during airborne, 4) timing between ball motion and limbs' coordination, and 5) damping mechanism during falling. An accurate kick can only be achieved through repetitive training. This underlines the need for athletes to master a safe landing technique that minimizes risk of injury during practice. Therefore, training should begin with learning a safe falling technique.

**Keywords:** 3D motion capture; full-body biomechanical modeling; X-factor; hip flexibility; whip-like movement; dispersion of impact load during falling.

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## 1. Introduction

The great attraction of soccer for millions of fans may trace down to the basic idea of the game: the goal – an idea that never ceases to fascinate. Comparing to many other sports, goals are relatively rare in soccer (in average <3 goals/game in FIFA world cups since 1960's [1]). Because of the rarity, soccer goals are extremely exciting. The game can be thought of as an improvised drama, where emotional tension is built over long periods only to be fully released when a goal is achieved. Especially, the goals achieved by applying flying techniques such as diving scorpion kick, bicycle kick, diving header and jumping side volley are source of rabid excitements. This uniqueness of soccer contributes to making the game the No. 1 sport worldwide [2-5]. Among all the techniques, the jumping side volley is, no doubt, one of the infrequent scoring skills that fans invariably desire to catch in their attending games. Unfortunately, few players have performed this skill during national or international tournaments.

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Jumping side volley is an acrobatic airborne-technique (Figure 1). One can see its rarity from European Championship 2016 (Euro 2016), only one out of 108 goals [6]. However, this rare skill has created breathtaking moments and cherished memories for players and fans. A classic example is Wendell Lira (Brazil) superb airborne side volley, which won the most prestigious FIFA Puskás Award 2015 [7]. In Euro 2016, Xherdan Shaqiri (Swiss) jumping side volley was selected as the best goal of the tournament [8]. The novelty of the skill (just like the acrobatic bicycle kick) is perchance rarity because these kicks are perceived as high-risk and low-return skills [9]. Regrettably, a scientific study on the skill has not been found in literature [4]. Relying on talent of athletes to improvise on the fly can hardly be considered as a viable learning strategy. Therefore, we have launched a preliminary study [10] to give an scientific overview of the kick, to identify key features of the skill and to formulate a scientific way of learning/training the technique. Specifically this preliminary study uses 3D motion capture technology to quantify the dominate factors contributing to the kick quality and to identify biomechanical elements that govern entrainment of jumping side volley in order to develop its coaching method.

**Figure 1.** Jumping side volley – a flying techniques for defeating goalies.

## 2. Materials and Methods

### *2.1. How to establish a lab test condition for mimicking the reality?*

Since the study was application-oriented investigation, the first challenge was how to get a realistic data? We went back to professional games to find a reasonable solution.

In reality, ball flying-in direction could be arbitrary. Figure 2 supplies four successful examples selected from professional soccer games. Example 1 (Figure 2a) shows that the player used his head to set a flying-in ball vertically and then performed a jumping side volley. In example 2 and 3 (Figure 2b – 2c), the player employed his chest and foot, respectively, to set a flying-in ball vertically for doing a jumping side volley. A vertically projectile ball can also be set by other players (Figure 2d, the goal keeper set a vertically projectile ball for a player). All the four examples demonstrate that the vertically projectile ball could be an often scenario for executing the jumping side volley. Therefore, for our study, the vertically projectile ball done by each subject was applied in our lab-based data collection.

### *2.2. 3D Motion Capture and Biomechnaical Modeling*

A 3D twelve-camera VICON MX40 motion-capture system (VICON Motion Systems, Oxford Metrics Ltd., Oxford, England [11]) was used to measure the jumping side volley using 42 reflective, 9mm markers on the body. The motion capture system tracked the markers at a rate of 200 frames/s. This capture rate has been widely applied in various complicated/elite sport-skills' analyses [12-16]. Figure 3 shows a 3D computer reconstruction of a single trial, including camera placement, capture volume, and a rendered stick figure. Markers were placed on subjects as follows: 1) four on the head, 2) trunk markers on the sternal end of the clavicle, xiphoid process of the sternum, C7 and T10 vertebrae, each scapula, left and right anterior superior iliac, posterior superior iliac, 3) upper-

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extremity markers on the right and left acromion, lateral side of upper arm, lateral epicondyle, lateral side of forearm, styloid processes of radius and ulna, and distal end of 3rd metacarpal bones, and 4) lower extremities markers on left and right lateral sides of thigh and shank, lateral tibial condyle, lateral malleolus, distal end of 5th metatarsal, calcaneus and big toe. For reducing potential injury risk, soft markers were applied for the tests. These compress (and decompress) easily, therefore, their influence on skill performance is negligible. Calibration residuals were determined in accordance with VICON's guidelines and yielded positional data accurate within 1 mm.

Additionally, three reflex markers (made from 3M reflective paper) were glued to the ball in order to quantify the soccer release speed.


**Figure 2.** Successful examples of jumping side volley in professional games. The common feature of the examples is a vertically projectile ball. The ball condition can be created by a player using (**a**) his head; (**b**) his chest; (**c**) his foot; or (**d**) set by another player.

VICON software triangulated positions of each marker and rendering them in three-dimensional computer space. The raw data collected was processed by a five-point smoothing filter. The five-point filter is a premier filter in time domain that reduces random noise while retaining a sharp step response [16]. It is widely applied in reducing noise from possible vibration of the markers during 3D motion capture of sports and arts performance [14, 17, 18]. The resultant data supplied primary information, such as marker position, position changes, velocities, and accelerations. From the marker-position data, anatomical landmarks were established that allowed modeling of the skeletal structure for each participant. Using basic physics, simple positional data were translated into skeletal movement. VICON software provide tools for building a 15-segment biomechanical model of the soccer kick (Figure 3) [19-22]. Model segments were identified as follows: head, upper trunk, lower trunk, upper arms, lower arms, hands, thighs, shanks and feet. The model calculated segment lengths, joint angles and ranges of motion (ROMs) for the joints [23, 24]. In such biomechanical modeling, inertial characteristics of the body are estimated using anthropometric norms found through statistical studies [25, 26]. The modeling enabled researchers to postulate motor control patterns. After model calculations, descriptive statistics (i.e. average and standard deviation) of body kinematic data (i.e. joint angles, joint ROMs and joints' coordination timing)and correlation analyses among the body kinematic data with ball release speed were performed by using EXCEL 2016 for finding the key/dominant factors governing entrainment of the jumping side volley.

Motion capture technology permits considerable freedom of movement for participants without negatively influencing their motor skill control. Taking advantage of this, we placed no restrictions on subjects' movements within the capture volume in an effort to preserve their normal "style". Given the rarity of individuals who have acquired this skill, we found only five male soccer players who could perform this skill. Two of them are Canadian and the others are Chinese. The anthropometrical characteristics and soccer experience are: body height 1.74±0.04 m, body weight 70.4±3.8 kg, age 22.0±1.6 years and training 15.8±1.5 years. The university human-subject committee scrutinized and approved the test as meeting the criteria of ethical conduct for research involving human subjects. The subjects were informed the testing procedures, signed consent forms, and voluntarily participated in the data collection. A total of 23 successful trials (i.e. the ball was accurately and powerfully kicked) were captured.

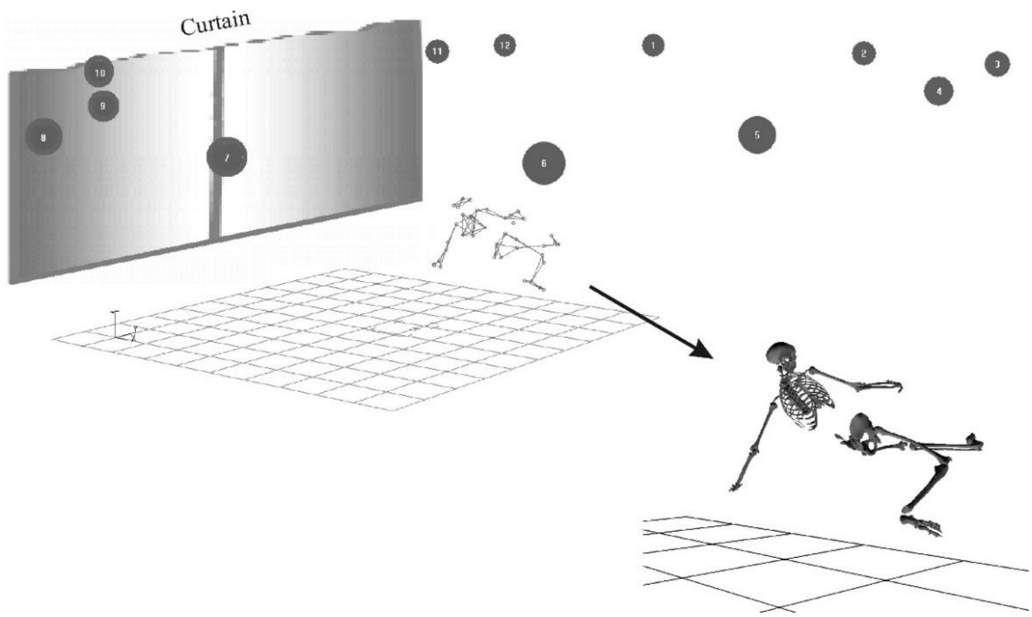


**Figure 3.** 3D motion capture reconstruction showing 12-camera placements and a wire frame mesh reproduction of a jumping side volley (left) and 15 segment biomechanical model built from the 3D data collected.

## 3. Results

Figure 4 shows that two events - take-off and ball contact - divide the jumping side volley into three phases: 1) the jumping phase, 2) the airborne phase, and 3) the landing phase. Our data reveal the following characteristics of the 1st phase. Before the volley, athlete's trunk and pelvis rotate away from the goal. During the takeoff, the non-kick-side (NKS) leg is raised, at the same time, the trunk reverses rotational directions and comes to twist toward the goal. In order to increase the range of motion (ROM) of trunk rotation, both arms abduct to near horizontal (over 80°, Table 1). Until the take-off, the ROM of trunk twist (commonly known as X-factor [27-29]) is about 40° (Table 1). At the end of the phase, the trunk-orientation approaches a more horizontal position (Figure 4). Correlation

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analyses confirm that X-factor ($\alpha$), angle between thighs ($\beta$) at take-off, and shoulder abduction during jumping are key/dominate factors, influencing the kick quality, i.e. the ball release speed (Figure 5**a** – 5**b**).

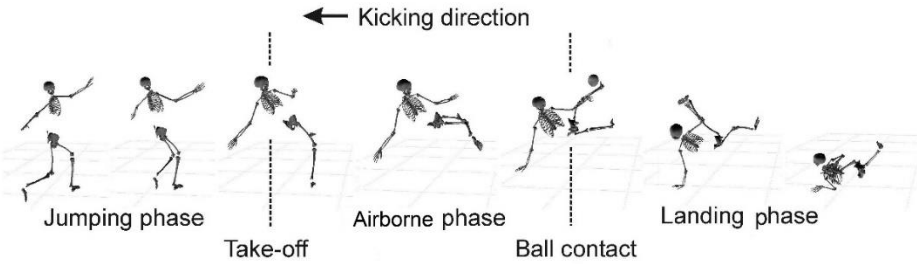


**Figure 4.** Phase identification based on 3D motion analysis data.

**Table 1.** Average and standard deviation of selected parameters and their correlation with the ball release speed.

| Selected Parameters | | Results | Correlation r |
|---|---|---|---|
| ROM (°) | Trunk Twist (X-factor $\alpha$) | 41.5±5.1 | 0.86 |
| | KS Hip (Flex/Ext) | 51.6±5.2 | 0.71 |
| | KS Knee (Flex/Ext) | 56.9±6.1 | 0.76 |
| | KS Ankle (Flex/Ext) | 11.6±2.2 | 0.52 |
| Angle (°) | Max Shoulder Abduction | 83.7±4.2 | 0.69 |
| | Take-off angle between thighs ($\beta$) | 75.2±13.0 | 0.82 |
| | Min KS knee angle | 84.1±9.6 | -0.75 |
| Coordination timing (%) | Trunk → KS hip | 83.2±4.1 | 0.57 |
| | KS hip → KS knee | 74.4±15.4 | 0.89 |

X-factor: the angle between shoulder line (upper trunk) and hip line (lower trunk)
Flex/Ext: Flexion/Extension, KS: Kick Side

One notable characteristics of the 2nd phase (i.e. the airborne phase) is the flexed kick-side (KS) leg and the extended NKS leg (Figure 5**c**). Both legs form a scissor-movement, i.e. they move in opposite directions. The correlation analyses approve that both the minimum angle and ROM of the KS knee are key factors, affecting the kick quality (Table 1). From the timing perspective, the KS hip-flexion starts when about 80% trunk twist toward the goal has finished. Similarly, the KS knee begins its extension after the KS hip finishing about 75% of its flexion (Table 1). Further, our data show that the explosive KS knee extension happens shortly before the ball contact, and is followed by an ankle flexion. Such a segmental coordination is the typical characteristics of a whip-like control, also found in the maximal instep kick and bicycle kick in soccer [4, 5, 19, 21]. The correlation analyses unveil that the sequential segment-coordination and is also a key contributor to the kick quality.

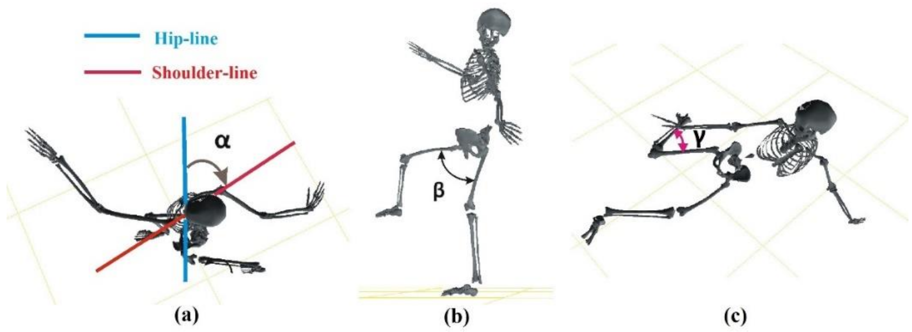


**Figure 5.** Key/dominate factors influencing kick quality. (**a**) X-factor $\alpha$ (top view); (**b**) Take-off angle between thighs $\beta$ (side view); (**c**) Minimum KS knee angle $\gamma$ (top-front view).

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The main issue in 3rd phase (i.e. the landing phase) is how to dissipate the impact load produced by the falling in order to avoid potential injuries. Our data reveal that the well-trained athletes apply multiple landings to share the impact loads for reducing the risk of injury. The 1st landing is the flexed arm-hand chain (like a spring) to do the 1st damping. The 2nd landing is the hip landing, followed by a body rolling, sharing the rest load among multiple contact points.

## 4. Discussion

Since this study focuses on coaching practice, the results should be coach-friendly. A coach-friendly study, in our vision, should supply explanations on: 1) scientifically-identified motor-control sequencing; 2) dominant factors contributing to the control of the motor skill; and 3) the most important thing is that the results can be understood by coach and applied by coach in practice. Therefore, based on numerous analyses of our 3D data, the following key factors have been selected for illustrating the secrets of the acrobatic skill-control in order to establish a practical way to learn and to train the jumping side volley:

- phase identification
- trunk rotary control
- hip flexibility
- lower-limb control
- upper-limb control
- coordination between upper- and lower-limbs.

Such a focused communication would help practitioners understanding the complex motor control in a timely efficient way.

The aims of the current study are: 1.) to quantify key/dominate factors contributing to the kick quality, and 2.) to identify biomechanical elements that govern entrainment of jumping side volley in order to develop its coaching method.

To the first goal, the following key/dominate factors are revealed: there are two key factors in phase 1: the twisting control of the upper body ($\alpha$) and the instance angle between the two thighs at take-off ($\beta$). The larger $\alpha$ and $\beta$ are, the more powerful is the kick. Actually, these two factors play a crucial role in laying a foundation for performing the whip-like control of the kick in phase 2. In conjunction with key factors in phase 2, the effects of $\alpha$ and $\beta$ will be elaborated below.

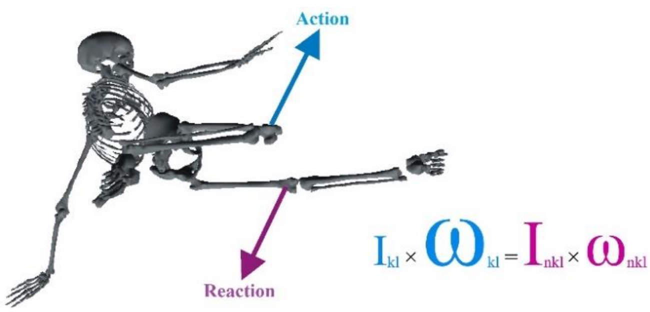


**Figure 6.** The asymmetric control of the legs during the airborne phase and their effects revealed by the Law of Conservation of Angular Momentum, i.e. the smaller the I, the faster the $\omega$; vice versa.

One notable feature of phase 2 is the asymmetric control of the legs, i.e. a multi-segment control of the kick leg vs. a quasi single-segment control of the non-kick leg. This asymmetric control results in a difference between the moments of inertia of the two legs. The difference is vital for forwardly accelerating the kick leg; as such, it influences the quality of the whip-like movement. In the airborne phase, human body follows the Law of Conservation of Angular Momentum. That means, the angular momentum of the forward action (the KS leg) equals the angular momentum of the backward reaction (the NKS leg). The flexed KS leg leads to a smaller moment of inertia (I), resulting in a faster

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forward motion in compare to the extended NKS leg (a larger I creates lower backward motion) (Figure 6). In conjunction with phase 1, we found that the whip-system of the jumping side volley consists of four segments: trunk, KS-thigh, KS-shank and kick foot. The whip-like kick is actually initiated in phase 1, beginning with trunk twisting toward the goal, followed by hip flexion, knee extension and ankle flexion, showing a sequential flow of energy and momentum transfer. It is well known that increasing the ROM of each segment will enhance the effect of whip-like movement [14, 19, 28-30]. Therefore, flexibility of hip and knees should be emphasized during training and the training should also pay attention to the segment coordination (i.e. the whip-like control). Of course, timing is the most crucial element for coordination training.

For training jumping side volley, one should pay attention to two aspects.

The first one is kick power. It is important to develop a full-body whip-like control (from trunk to KS foot) for increasing kick power. For reaching this goal, jumping training should emphasize the upper-body twisting control, and the flexibility training should focus on the hip (one should always remember that the larger the $\beta$ is, the more powerful is the kick). The airborne training should establish an asymmetrical control of legs as well as the ROM training of the KS-leg joints, i.e. KS leg performing a whip-like control and NKS leg remaining extended.

The second aspect is the kick accuracy and timing. Those of us who are involved in the coaching practice know well that there is no shot-cut. It requires a repetitive training. The jumping side volley is considered as high risk because of the evitable falling to the ground, i.e. a realistic fear of injury to players/learners. We know that the feet and legs are naturally designed for absorbing landing impacts, but the arms and body are not. What does that mean? That means, for learning the jumping side volley, we have to begin with phase 3, i.e. the learning and training of a safe falling technique, e.g. the multiple-landing technique revealed by the current study. Mastering a safe landing technique is the only way that can ensure the repetitive training for improving the kick accuracy and timing as well as the kick power.

## 5. Conclusions

The current study indicates that entraining jumping side volley should focus on increasing the flexibility of the hip, the efficiency of the whip-like movement of the proximal to distal acceleration of the kicking leg, and the damping mechanism during falling. Accurate timing is vital for a successful kick and can only be achieved through repetitive training. This underlines the need for athletes to learn a safe landing technique that minimizes risk of injury during practice. Therefore, training should begin with phase 3 – mastering a safe falling.

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**Author Contributions:** G.S., X.Z., F.L. and Y.Y. conceived and designed the experiments; G.S. and X.Z. performed the experiments; G.S., X.Z., F.L. and Y.Y. analyzed and discussed the data; G.S. and X.Z. contributed reagents/materials/analysis tools; F.L. and Y.Y. prepared figures; G.S. and X.Z. wrote the paper; all authors contributed to the revisions and proof reading of the article.

**Conflicts of Interest:** The authors declare no conflict of interest. The founding sponsors had no role in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

## References

1. FIFA. Average number of goals scored per game at the FIFA World Cup from 1930 to 2018. 2020 [cited 2020 Janunary 26]; Available from: https://www.statista.com/statistics/269031/goals-scored-per-game-at-the-fifa-world-cup-since-1930/.
2. Hyballa, P., The art of flying. Success in Soccer, 2002. 5: p. 19-26.
3. Reilly, T. and M. Williams, Science and soccer. 2nd ed. 2003, London: Routledge.

4. Shan, G. Biomechanical Know-how of Fascinating Soccer-kicking Skills–3D, Full-body Demystification of Maximal Instep Kick, Bicycle Kick & Side Volley. in Proceedings of the 8th International Scientific Conference on Kinesiology, Zagreb, Opatija, Croatia. 2017.
5. Shan, G., et al., Biomechanics of coaching maximal instep soccer kick for practitioners. Interdisciplinary Science Reviews, 2019. 44(1): p. 12-20.
6. YouTube. All 108 UEFA EURO 2016 goals: Watch every one. 2016 [cited 2020 Jan. 26]; Available from: https://www.youtube.com/watch?v=a4Qvh6VIoSs.
7. FIFA. FIFA Puskás Award. 2019 [cited 2019 June 16]; Available from: https://www.fifa.com/the-best-fifa-football-awards/puskas-award/.
8. UEFA. Top ten goals of UEFA EURO 2016 revealed. 2016 [cited 2018 September 19]; Available from: https://www.uefa.com/uefaeuro-2020/news/0253-0d7e907eeaa5-b7d7554f6864-1000--top-ten-goals-of-uefa-euro-2016-revealed/.
9. Shan, G., et al., Bicycle kick in soccer: is the virtuosity systematically entrainable? Science Bulletin, 2015. 60(8): p. 819-821.
10. Smith, P.G., R.H. Morrow, and D.A. Ross, Preliminary studies and pilot testing, in Field Trials of Health Interventions: A Toolbox. 3rd edition. 2015, OUP Oxford.
11. VICON. The Most Precise MoCap Ecosystem. 2020 [cited 2020 Jan 26]; Available from: https://www.vicon.com/applications/engineering/.
12. Smith, S.L. Application of high-speed videography in sports analysis. in Ultrahigh-and High-Speed Photography, Videography, and Photonics. 1993. International Society for Optics and Photonics.
13. Chang, S.T., et al., An innovative approach for Real Time Determination of Power and Reaction Time in a Martial Arts Quasi-Training Environment Using 3D Motion Capture and EMG Measurements. Archives of Budo, 2011. 7(3): p. 185-196.
14. Wan, B., et al., Hammer Throw: a Pilot Study for a Novel Digital-route for Diagnosing and Improving Its Throw Quality. Applied Sciences, 2020. 10(6): p.1922.
15. Li, S., et al., The relevance of body positioning and its training effect on badminton smash. Journal of sports sciences, 2017. 35(4): p. 310-316.
16. Liu, Y., et al., Biomechanical analysis of Yang's spear turning-stab technique in Chinese martial arts. Physical Activity Review, 2020. 8(2): p. 16-22.
17. Michalowski, T., Applications of MATLAB in Science and Engineering. 2011: BoD–Books on Demand.
18. Yu, D., et al., Biomechanical characteristics of the axe kick in Tae Kwon-Do. Archives of Budo, 2012. 8(4): p. 213-218.
19. Visentin, P., et al., A pilot study on the efficacy of line-of-sight gestural compensation while conducting music. Perceptual and motor skills, 2010. 110(2): p. 647-653.
20. Shan, G. and P. Westerhoff, Full-body kinematic characteristics of the maximal instep soccer kick by male soccer players and parameters related to kick quality. Sports Biomechanics, 2005. 4(1): p. 59-72.
21. Shan, G., Influences of Gender and Experience on the Maximal Instep Soccer Kick. European Journal of Sport Science, 2009. 9(2): p. 107-114.
22. Shan, G. and X. Zhang, From 2D Leg Kinematics to 3D Full-body Biomechanics – The Past, Present and Future of Scientific Analysis of Maximal Instep Kick in Soccer. Sports Medicine Arthroscopy Rehabilitation Therapy Technology, 2011. 3: p. 23.
23. Shan, G., et al., Regression equations for estimating the quality of maximal instep kick by males and females in soccer. Kinesiology, 2012. 44(2): p. 139-147.

24. Shan, G., et al., Biomechanical analysis of maximal instep kick by female soccer players. Journal of Human Movement Studies, 2005. 49: p. 149-168.
25. Wan, B. and G. Shan, Biomechanical modeling as a practical tool for predicting injury risk related to repetitive muscle lengthening during learning and training of human complex motor skills. SpringerPlus, 2016. 5(1): p. 441.
26. Shan, G. and C. Bohn, Anthropometrical data and coefficients of regression related to gender and race. Applied ergonomics, 2003. 34(4): p. 327-337.
27. Winter, D.A., Biomechanics and motor control of human movement. 2009: John Wiley & Sons.
28. Shan, G., et al., Quantification of Golfer-club Interaction and Club-type's Affect on Dynamic Balance during a Golf Swing. International Journal of Performance Analysis in Sport, 2011. 11: p. 417-426.
29. Zhang, X. and G. Shan, Where do golf driver swings go wrong? - Factors Influencing Driver Swing Consistency. Scandinavian Journal of Medicine and Science in Sports, 2014. 24(5): p. 749-757.
30. Zhang, Z., et al., The influence of X-factor (trunk rotation) and experience on the quality of the badminton forehand smash. Journal of human kinetics, 2016. 53(1): p. 9-22.
31. Wąsik, J., et al., The influence of gender, dominant lower limb and type of target on the velocity of taekwon-do front kick. Acta of Bioengineering and Biomechanics, 2018. 20(2): p. 133-138.