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Review

Biomechanics of Table Tennis: A Systematic Scoping Review of Playing Levels and Maneuvers

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Received: 1 July 2020; Accepted: 24 July 2020; Published: 28 July 2020

Abstract: This present study aims to review the available evidence on the biomechanics of table-tennis strokes. Specifically, it summarized current trends, categorized research foci, and biomechanical outcomes regarding various movement maneuvers and playing levels. Databases included were Web of Science, Cochrane Library, Scopus, and PubMed. Twenty-nine articles were identified meeting the inclusion criteria. Most of these articles revealed how executing different maneuvers changed the parameters related to body postures and lines of movement, which included racket face angle, trunk rotation, knee, and elbow joints. It was found that there was a lack of studies that investigated backspin maneuvers, longline maneuvers, strikes against sidespin, and pen-hold players. Meanwhile, higher-level players were found to be able to better utilize the joint power of the shoulder and wrist joints through the full-body kinetic chain. They also increased plantar pressure excursion in the medial-lateral direction, but reduced in anterior-posterior direction to compromise between agility and dynamic stability. This review identified that most published articles investigating the biomechanics of table tennis reported findings comparing the differences among various playing levels and movement tasks (handwork or footwork), using ball/racket speed, joint kinematics/kinetics, electromyography, and plantar pressure distribution. Systematically summarizing these findings can help to improve training regimes in order to attain better table tennis performance.

Keywords: kinematics; kinetics; table tennis; racket

1. Introduction

Table tennis is a competitive sport which requires technical preparation, tactics, as well as mental and motor training [1]. Players with higher technical capability demonstrate good coordinated movement with controlled strike power, which yield adequate speed and spin on the ball in limited decision time [2,3]. To master the stroke, professional players have to rotate the trunk efficiently and place excellent foot drive in response to various ball conditions [2]. Whole-body coordination plays an important role in table tennis, as the biomechanics of lower extremities is closely related to the upper limb performance [4]. An incorrect technique would alter movement mechanics and thus joint loadings that are related to risk potential of injury. A retrospective study found that about one-fifth of table tennis players suffered from shoulder injuries [5]. Although numerous studies had investigated the biomechanics of table tennis maneuvers, their methods and protocols were generally inconsistent.

Therefore, direct comparison across studies is not feasible. Furthermore, players of different skill levels may perform different table tennis maneuvers with unique techniques and patterns. To identify the common characteristics of higher-level players, an investigation has to be conducted properly mapping playing levels with different maneuvers. Such information can help in designing sport-specific training programs in table tennis.

Biomechanical reviews of various sports, such as football [6,7], tennis [8,9], and swimming [10–12] have identified strategies to improve sports performance and prevent injuries. While previous review articles summarized physiological demands of table tennis players [13,14], conducted match analysis [15–17], and reviewed contemporary robot table tennis [18,19], there have been no sufficient reviews on the biomechanics of table tennis. There was an article reviewing the science (including biomechanics) of major racket sports [20], however its focus was not on limb movements and the joint loading of different skill levels.

A systematic scoping review accounts for the published evidence over a broad topic by summarizing, mapping, and categorizing key concepts that underpin a particular research area using a systematic protocol [21]. Such a review looks into the literature which has demonstrated high complexity and heterogeneity. The objective of this systematic scoping review was to identify recent advances in testing protocols, variables, and biomechanical outcomes regarding table tennis maneuvers and performance. The scope of sports biomechanics in table tennis is board, which has not been comprehensively reviewed. The objectives of this review were guided by the following research questions:

1. How was the biomechanics of table tennis movements analyzed?
2. What were the biomechanical differences between higher- and lower-skilled players?
3. What were the biomechanical differences among various table tennis maneuvers?

The principle focus or concept of this review pertained the categorization of biomechanical variables while the primary context was to summarize the playing skill levels and maneuvers. This study can contribute to the field of sports science by identifying key ideas for performance improvement and identify research gaps in table tennis.

2. Materials and Methods

The searches of the scoping review were designed and conducted by the first author. The first author and the third author conducted the abstract and full-text screening, and data extraction. Any disagreements were resolved by seeking consensus with the second author, and all authors conducted a final check of the review. Electronic literature searches of electronic databases, including ISI Web of Science (excluding patents, from 1970), Scopus (from 1960), and PubMed (from 1975), were performed on 13 July 2020.

The searches were conducted using the keywords "table tennis" AND the terms "biomechan*" or "kinematics" or "kinetics" in the topic field, but NOT "catalyst", "catalysis", "enzyme", "biochemistry", "oxidase", "acid", "biochemistry", "colorimetric", or "nanocomposite" to rule out a similar topic in biochemistry. The titles, abstracts, and then full-text of the papers were screened based on the following inclusion criteria: (1) published in English; (2) research article in peer-reviewed journals; (3) biomechanical studies on table tennis with experiments involving adult players; (4) original research articles either case-control or longitudinal studies investigating playing levels or differences in maneuvers. Studies were excluded if the articles (1) did not consider any table tennis moves, (2) considered participants with disability, musculoskeletal problems, or rehabilitation, (3) only considered physical, psychological attributes or tactics, (4) were not original peer-reviewed articles, (5) studied table tennis robots, or (6) used simulations or theoretical models. The searching selection process is summarized in Figure 1. There was no disagreement among authors in the selection of studies eligible for the review. The following information was extracted: bibliographic details, sample size, characteristics of participants, inclusion and exclusion criteria of studies, and experimental settings.

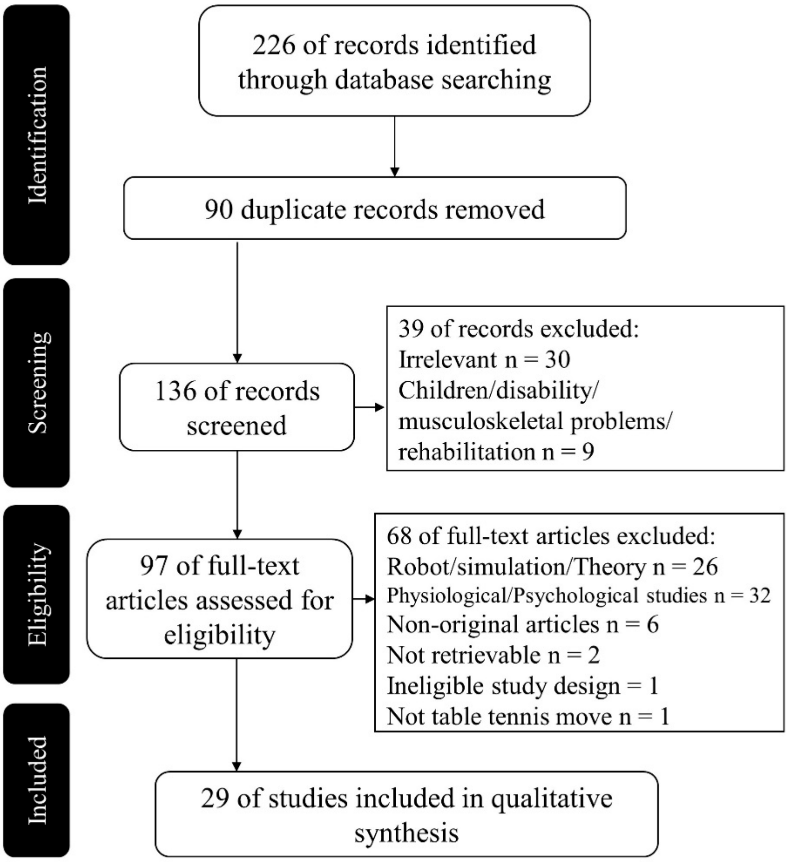

Figure 1. Flowchart of the systematic search and selection process.

3. Results

3.1. Search Results

An initial search identified 226 studies. After pooling the results and removing duplicates, 136 articles were screened for titles and abstracts. Finally, there were 29 studies successfully meeting the eligibility criteria (Figure 1). The studies were excluded because they were irrelevant (n = 30); they involved players with disabilities, musculoskeletal problems, or children (n = 9); they used robotic players, simulations or theoretical calculations (n = 26); they ocused on psychological issues, tactics, decision-making, coaching, cardiopulmonary or metabolic assessments (n = 32); they were survey, conference paper, review, and expert comment papers (n = 6). One study did not fall into the inclusion criteria of study design whilst another study did not examine any table tennis move. The full-text of one article could not be retrieved because it was too old and the journal was closed down [22]. One study was not retrievable with the given digital object identifier (DOI) [23].

The participant characteristics and study designs of the 29 included articles are summarized in Tables 1 and 2, respectively. In brief, participant characteristics, test protocols, and outcome variables of each article were summarized according to playing levels (n = 12), movement tasks (handwork, n = 6; footwork, n = 4; ball/serve against, n = 8) and other factors (n = 4) to identify performance determinants. Six included studies considered multiple factors on different servings with handwork [1,2] or playing level [24,25], racket mass with ball frequency [26], and footwork with footwear [27]. Furthermore, the categorization of dependent and independent variables are mapped in Figure 2. Key findings of the included studies related to playing levels and maneuvers are provided in Tables 3 and 4.

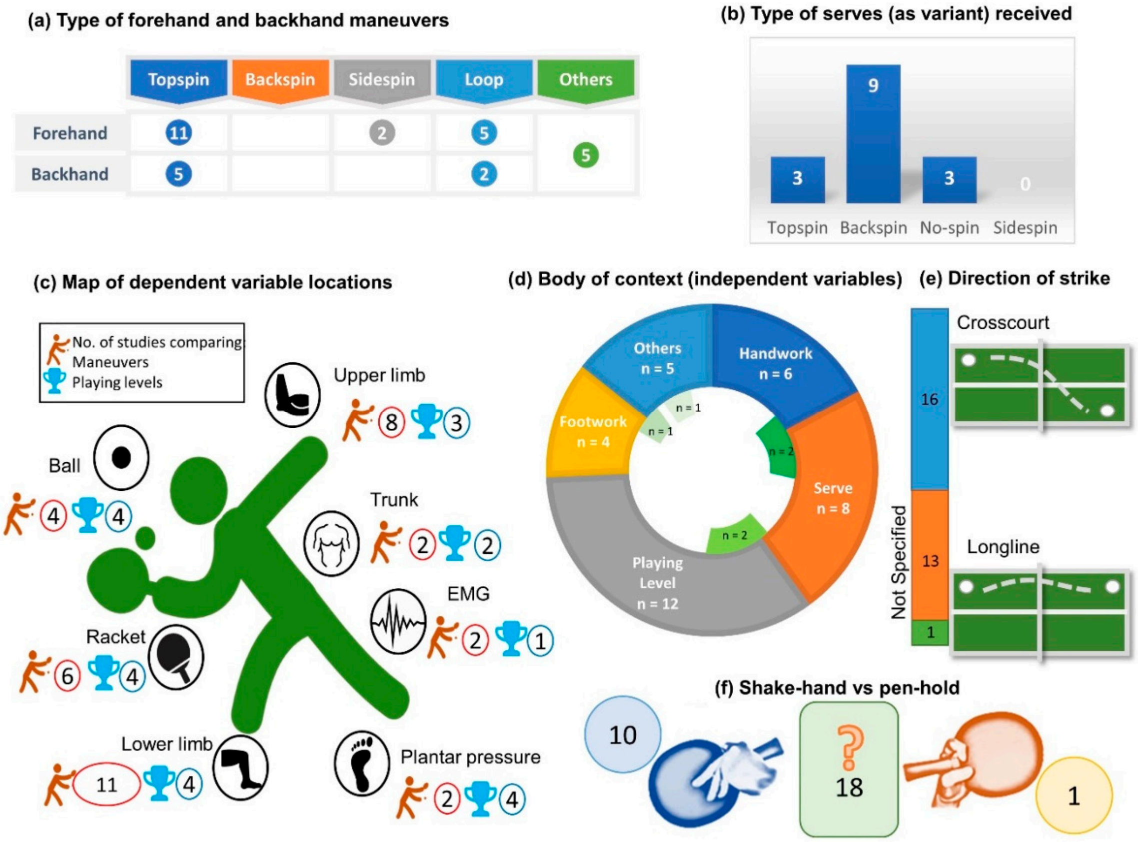

Figure 2. A scoping review map summarizing: (**a**) types of forehand and backhand maneuvers; (**b**) types of serves (as variant) to hit back; (**c**) map of dependent variables comparing the number of studies between topics on maneuvers and playing levels; (**d**) body of context (independent variables), the n-values in the interior circle denote number of studies with multiple independent variables between or within the factors stated on the exterior circle; (**e**) direction of strike; and (**f**) shake-hand vs pen-hold.

3.2. Classification of Movement Stage/Phase

While some included studies adopted the maximum or average values of performance outcome of strokes, the majority of the studies divided stroke into movement sub-phases or targeted to selected instants for subsequent analysis. Typically, the stroke was classified into backswing and forward-swing phases, targeted on the specific time points at the termination, backward-end and forward-end [1,3,28–34]. A few included studies [2,24,26,33,35,36] focused on the instant at ball impact which was used to determine the velocity of the racket and ball, while some other included studies investigated the biomechanics at pre-impact and post-impact stages [24,36–38], and over a longer period of time before and after the instant of ball contact [1,2,38,39]. Some included studies endeavored that pelvic and hip rotations were correlated with the racket velocity at impact and thus focused on the starting time of the pelvic forward rotation [36,37]. To sum up, the included studies often investigated the biomechanical parameters at the instant of ball or racket impact as well as the maximum or average value during the time before and after the ball impact.

3.3. Ball and Racket Performance

Eight included studies examined the effects of ball and racket mechanics as well as serve techniques on table-tennis performance [1,2,24–26,33,35,37], and some of these studies also compared the influences of different handworks [1,2] and playing levels [24,25]. Common variants included the type of ball spin [1,2,33,35,37,39] and the spin rate [24,25]. Moreover, seven included studies investigated ball, racket, and serve as outcome measures instead of variants [31,38,40–45].

Ball speed, accuracy, and repeatability were suggested to be the key indicators of playing level. Ball speed and accuracy were significantly correlated with player ranking in a competition [43]. Higher-level players produced higher ball speed and accuracy, which could be due to significantly shorter duration and variability of duration in the forward swing phase [31,32,38,41]. However, Iino and Kojima [24] found that racket speed at impact was not significantly different between playing levels (advanced vs. intermediate), although players with higher-level can rotate the trunk effectively to produce a greater racket acceleration at ball impact. Yet, Iino and Kojima [24] imposed a stringent significance level using a Bonferroni correction. Similarly, Belli et al. [40] found that while there was only a slight difference in ball speed comparing higher and lower-level players, players with higher-level demonstrated higher accuracy of ball target placement and made fewer errors in training and competition. On the other hand, inexperienced players showed higher inconsistency in ball speed and accuracy during within- and between-day trials [43]. Compared to the intermediate players, advanced players showed smaller variance of joint angle that affected the racket vertical angle during forehand topspin stroke [41]. Furthermore, a lower variability in the racket orientation and movement direction could be the reason for more successful returns and higher accuracy of the ball bounce location [38]. An uncontrolled manifold analysis suggested that higher-level players exploited higher degree of redundancy to maintain a similar racket angle at ball impact [41]. In brief, higher-level players exhibited higher accuracy and reproducibility on ball and racket mechanics but may not necessarily produce higher ball speed than lower-level players.

Compared to the topspin serves, returning backspin serves demonstrated significantly higher resultant and vertical racket velocities at ball impact [35,37], which could be contributed greatly by the wrist extension [35]. A possible explanation for this is that backspin serves tend to be treated back-low owing to the spin, resulting in a greater upward velocity of the shoulder joint center [37]. Moreover, peak shoulder torques in all directions, as well as elbow valgus torques, were significantly larger against backspin, in addition to the peaks of upper trunk right axial rotation and extension velocities [37]. Returning a spinning ball also alters the moving distance and velocity of the racket in the upward-downward direction, as compared to an ordinary stroke or a stroke with higher power. Hitting back a backspin serve could be more demanding than a topspin serve.

In addition, biomechanical differences between returning light and heavy backspin serves were assessed by two included articles from the same research group [24,25]. They produced different rates of ball backspin (11.4 vs. 36.8 revolutions/s) for light and heavy spin conditions. The heavy spin would direct the racket face to be more open [24]. Furthermore, their results found higher maximum loading at elbow and shoulder joints which might result in higher work done at the racket arm [25]. However, higher-level players showed a higher amount of energy transfer of the elbow for a light spin compared to intermediate players, but the opposite was true for the heavy spin [25], implying significant interaction effect between ball spin and playing level. The influence of racket mass and ball frequency were investigated by Iino and Kojima [26], who suggested that a heavier racket could impose higher demand on wrist extension torque, but did not influence trunk and racket arm kinematics and kinetics. A frequent ball serve could result in a lower racket speed at impact possibly since the pelvis and upper trunk rotations were not responsive enough. Table tennis players managed to identify the differences in ball spin, frequency, and mass, and accommodated by tilting the racket face angle and adjusting the power output of upper extremity.

Table 1. Participant characteristics of reviewed studies.

Author (Year)	Participants Information Sample Size; Age (years); Height (cm); Weight (kg)	Group/Level *	Inclusion Criteria (IC)/Exclusion Criteria (EC)
Bankosz and Winiarski (2017) [1]	n = 12F; 20.0 (5.5);167.2 (6.9); 55.3 (6.2)	Players in high-level sports training and performance	IC: 1st 16 in their category of age; EC: NS
Bankosz and Winiarski (2018) [2]	n = 10F; 16.0 (2.5); 165 (6); 54.4 (3.2)	Junior elite players	IC: Top 16 junior players EC: NS
Bankosz and Winiarski (2018) [39]	Junior, n = 4F; 18.0 (0.5); 167.7 (5.7); 52.0 (3.6) Senior, n = 6F; 24.8 (3.2); 168.3 (6.3); 64.5 (2.4)	Junior and senior high sport skill players	IC: Top 16 TT players in Poland. EC: NS
Bankosz and Winiarski (2020) [33]	n = 7M; 23 (2); 178 (3); 76.5(8)	Top-ranked international players	IC: Top 10 TT players in Poland. EC: NS
Belli et al. (2019) [40]	Local, n = 9M; 24.3 (2.6); 174.6 (3.3); 68.1 (5.7); Regional, n = 10M; 23.9 (1.8); 176.9 (2.1); 79.8 (3.1)	Local group: 2.2 (0.3) yExp, 3.2 (0.5) hrWTR egional group: 7.5 (0.9) yExp, 10.0 (0.9) hrWT	IC: Local: low experience, w/o participation in tournaments; Regional: <5 years training, completed regional and national tournament
Fu et al. (2016) [3]	Intermediate, n = 13M; 21.2 (1.6); 175.2 (2.4); 69.1 (4.1); Superior, n = 13M; 20.1 (0.9); 174.8 (2.5); 66.9 (5.1)	National level Intermediate: (Div. II) 10.2 (1.9) yExp Superior: (Div. II) 13.4 (1.2) yExp	IC: NS EC: Previous lower extremity and foot disease or deformity, injury in the last 6 months
Ibrahim et al. (2020) [44]	n = 16M; 21.5 (1.27); 168 (56); 61.59 (8.60)	Collegiate players, min 3 yExp	IC: right-handed and shake-hand grip EC: NS
Iino et al. (2008) [35]	n = 11M; 21.1 (4.4); 171 (7); 66.3 (8.1)	International and collegiate players	IC: Shakehand grip attacking players EC: NS
Iino and Kojima (2009) [24]	Intermediate, n = 8M 20.6 (1.5); 170 (8); 59 (5.7) Advanced, n = 9M 20.6 (1.2); 171 (6); 66.2 (9.5)	Intermediate 7.4 (1.8) yExp Advanced 11.2 (0.8) yExp	IC: Intermediate: not qualified for national tournaments, Division III collegiate Advanced: qualified for national tournaments, Division I collegiate EC: NS
Iino and Kojima (2011) [25]	Intermediate, n = 8M 20.6 (1.5); 170 (8); 59 (5.7) Advanced, n = 9M 20.6 (1.2); 171 (6); 66.2 (9.5)	Intermediate7.4 (1.8) yExpAdvanced11.2 (0.8) yExp	IC: Intermediate: Div. III collegiate Advanced: Div. I collegiate EC: NS
Iino and Kojima (2016) [26]	n = 8M 20.6 (1.3); 170 (4); 63.1 (5.7)	Advanced players 13.0 (1.7) yExp	IC: Div. I collegiate team in Kanto Collegiate TT League in Japan; Offensive players; use shake hands grip rackets; EC: NS
Iino and Kojima (2016) [37]	n = 10M 20.6 (1.3); 171 (5); 61.6 (5.7)	Advanced skill players 12.8 (2.4) yExp	IC: Qualified for national level TT competitions in high school or college; EC: NS
Iino et al. (2017) [41]	Intermediate, n = 8M 20.9 (0.9); 173 (7); 62.5 (6.3); Advanced, n = 7M 20.4 (1.3); 172 (7); 65.3 (5.4)	Intermediate (Div. III) 7.8 (1.0) yExp Advanced (Div. I) 11.3 (2.2) yExp	IC: Intermediate: not qualified for national tournaments Advanced: qualified for national tournaments EC: NS
Iino (2018) [36]	n = 18M; 20.7 (1.1); 171 (5); 64.0 (7.6)	Advanced players 12.2 (2.2) yExp	IC: Div. I or II collegiate players EC: NS
Lam et al. (2019) [4]	n = 15M; 23.6 (2.2); 180 (4); 72.3 (6.2)	Div. I players	IC: NS; EC: lower extremity injury in the last 6 months
LeMansec et al. (2016) [43]	Inexperience, n = 18M 19.5 (0.9); 176.9 (5.9); 69 (6.4); Advanced, n = 14M; 30.7 (11.3); 178.3 (6.2); 74 (12.3); Expert, n = 20M; 28.4 (6.7); 178.9 (6.2); 74.5 (9.7)	Inexperience Advanced: 13.4 (5.6) yExp 4.1 (2.3) hrWT Expert: 19.8 (6.8) yExp 10.4 (7.9) hrWT	IC: Inexperience: students w/o experience in TT; not ranked in the Federation of TT; Advanced: participated in regional championship; Expert: participated in National or international competition; EC: NS
LeMansec et al. (2018) [46]	n = 14M; 27.1 (4.9);177.5 (5.3); 73.5 (8.4)	National level players 4.7 (1.9) hrWT	IC: Official competition players in the national championshipEC: Lower limb pain in last 2 years

Table 1. *Cont.*

Author (Year)	Participants Information Sample Size; Age (years); Height (cm); Weight (kg)	Group/Level *	Inclusion Criteria (IC)/Exclusion Criteria (EC)
Malagoli Lanzoni et al. (2018) [45]	n = 7M; 22.2 (3.2); 177.4 (4.2); 72.9 (11)	Competitive player: 10.2 (2.5) yExp	IC: 1st and 2nd national league players and ranked among 1st 200; EC: Consume caffeine last 4 h
Meghdadi et al. (2019) [47]	Healthy, n = 30M; 24 (2.59); 176 (7.81); 74 (5.82); Syndromic, n = 30M; 25 (2.29); 174 (7.06); 75 (5.50)	National-level players: Healthy: 5 (2.11) yExp; Syndromic: 6 (1.97) yExp	IC: top 100 list of Federation and active in League; right-handed. Syndromic: impingement on dominant side; EC: History of shoulder dislocation, surgery, occult/overt instability, symptoms on cervical spine, rotator cuff tendinitis, documented injuries/pathology to shoulder
Qian et al. (2016) [28]	Intermediate, n = 13M 21.2(1.6); 175.2(2.4); 69.1 (4.1); Superior, n = 13M 20.1 (0.9); 174.8 (2.5); 66.9 (5.1)	Intermediate (Div. III) 10.2 (1.9) yExp Superior (Div. I) 13.4 (1.2) yExp	IC: NS EC: Lower extremity and foot disease or deformity, injury for the last 6 months
Shao et al. (2020) [34]	Amateur, n = 11M; 20.8 (0.6); 174.2 (1.4); 62.4 (3.5) Prof., n = 11M; 21.6 (0.4); 173.5 (1.7); 63.7 (4.2)	Amateur: university students: 0.4 (0.2) yExp; Prof.: Div. I players: 14.2 (1.4)	IC: right-handed, Prof.: Div. I players; EC: any previous lower limb injuries and surgery or foot disease for at least 6 months
Sheppard and Li (2007) [38]	Novice, n = 12(NS); 22.2 (5.6); NS; NS; Expert, n = 12(NS); 21.7 (2.9); NS; NS	Novice: university population; Expert: table tennis club and sports center players	IC: right-handed, normal or corrected vision; Expert: at least years of experience and play at least 2 h per week; EC: no physical impairment
Wang et al. (2018) [29]	Amateur, n = 10M Elite, n = 10M NS; NS; NS	NS	IC: NS; EC: lower extremity, foot diseases/deformity; Injury in the past 6 months
Yan et al. (2017) [27]	n = 8M; 21.9 (1.1); 173.1 (4.2); 62.8 (2.7)	Collegiate players	IC: right-handed, second grade EC: no history of serious injury to lower limb; did not engage in vigorous exercise 24 h before experiment
Yu et al. (2018) [30]	n = 10F 21.6 (0.3); 164 (3); 54.2 (2.8)	Advanced 15.8 (1.7) yExp	IC: Div. I players EC: NS
Yu et al. (2019) [48]	n = 12M; 20.64 (1.42); 174 (3); 67.73 (3.31)	Elite national level players	EC: No previous lower limb injuries and surgeries or foot diseases
Yu et al. (2019) [32]	Beginners, n = 9M; 22.7 (1.62); 175 (4.6); 73.7 (3.1); Prof., n = 9M; 25.5 (1.24); 175 (5.3); 74.6 (2.5)	University TT team Beginners: 0.45 (0.42) yExp; Prof.: 14.8 (1.57) yExp	EC: free from any previous lower limb injuries, surgeries or foot diseases in the past 6 months.
Zhang et al. (2016) [31]	Novice, n = 10M 23.1 (4.1); NS; NSExpert, n = 10M 24.1 (1.6); NS; NS	Novice: university population Expert: prof. from TT teams and clubs	IC: NS EC: Novice: w/o formal training
Zhou (2014) [42]	n = 18M 22.3 (1.8); 172.7 (5.1); 64.6 (5.8)	Physical education major	IC: Played table tennis for more than 5 years EC: NS

* The names of the level or group are adopted from the included studies. Numbers in brackets denote standard deviation. M: male; F: female; Number in bracket denotes standard deviation. NS: not specified; yExp: year of experience; Div: division; h: hours; hrWT: hours per week training; TT: table tennis; Prof.: professionals; w/: with; w/o: without.

3.4. *Upper Limb Biomechanics*

There were eight included studies targeting handwork as the variant, while two of them co-variated with different serves (Table 2). Higher racket speed and faster ball rotation were the key attributes of attacking shots and this could be determined by the kinematics/kinetics of upper extremity as well as the efficiency of energy transfer through the upper arm [25,49]. Higher-level players showed significantly larger maximum shoulder internal rotation, elbow varus, and wrist radial deviation torques, in addition to the maximum joint torque power at shoulder joint in both internal and external rotation directions [25]. Higher angular velocity of the wrist joint contributed to a higher ball and racket speed during drop shot services, while that also produced higher racket speed during long shot services [44].

Moreover, higher-level players rotated the lower trunk efficiently contributing to higher racket speed at ball impact [24]. Meanwhile, the racket horizontal velocity at ball impact was related to the hip axial rotation torque at the playing side (i.e., racket side), while the racket vertical velocity was correlated with backward tilt torques and upward hip joint forces [36]. In contrast, players with shoulder impingement syndrome had sub-optimal coordination and movement patterns of the shoulder girdle [47]. These players significantly reduced muscle activity of the serratus anterior and supraspinatus, which was compensated by increasing overall muscle activity and early activation of upper trapezius [47]. Whole-body coordination and movement would play an important role in driving a speedy ball impact.

Comparing forehand and backhand strokes, racket speed during ball impact was similar but presented differences in the upward and forward velocity components [1]. Forehand stroke lasts slightly longer duration for whole movement cycle and individual phases, and noticeably longer total traveling distance of the racket. This could be because forehand had greater body involvement while the arm and trunk range of motion (RoM) in backhand stroke is limited. Forehand stroke may produce more energy, whilst a longer backswing phase in the high-force condition may generate higher force and longer contact time with the balls [1]. The racket velocity produced by forehand and backhand strokes could be different. During forehand stroke, racket velocity was correlated with the angular velocities of internal arm rotation and shoulder adduction, whereas the racket velocity was correlated with the angular velocities of arm abduction and shoulder rotation during a backhand stroke [2].

A longline forehand topspin produced larger ball rotation, compared to the crosscourt topspin shot. At the instant of the maximum velocity of racket in a forehand topspin stroke, players put their racket more inclined whilst maintaining a more flexed knee and elbow posture, in addition to a more pronounced trunk rotation [45]. Other maneuvers including loop, flick, fast break, and curling ball were also studied [35,42,46]. Compared to curving balls, Zhou et al. [42] suggested that fast breaking significantly reduced racket speed during ball impact. While the flick maneuver was specified as an attack when the ball is closed to the net, there were no detailed explanations on the moves of the fast break and curling ball in which we believed that they could be the flick/drop shot and topspin/sidespin loop maneuvers, respectively. On the other hand, Le Mansec et al. [46] demonstrated that aggressive strokes required greater muscle activities. During smash, biceps femoris, gluteus maximus, gastrocnemius, and soleus muscles were highly activated. Forehand topspin with more power or spin produced significantly higher muscle activation of biceps femoris and gluteus maximus muscles compared to other maneuvers, including backhand top, forehand smash, and flick.

3.5. Lower Limb Biomechanics

Four included studies investigated different footwork targeting side versus cross-step [4], long versus short chasse step [48], stepping directions and friction [27], and squatting [30], as shown in Tables 1 and 4, while one study compared players of different levels performing a cross-step [34]. Lam et al. [4] identified that both side-step and cross-step footwork produced significantly higher ground reaction force, knee flexion angle, knee moment, ankle inversion and moment compared with one-step footwork, in addition to a significant higher peak pressure on the total foot, toe, first, second and fifth metatarsal regions. On the other hand, long and short chasse steps during a forehand topspin stroke were compared [48]. Long chasse steps produced an earlier muscle activation for vastus medialis, quicker angular velocity, and larger ankle and hip transverse RoM, whereas larger ankle coronal RoM and hip sagittal RoM compared with the short chasse steps [48]. A stable lower limb support base is another important attribute to tackle serve. Yu et al. [30] compared a squat serve with stand serve and found that squat serve produced larger angles and velocities of hip flexion, adduction, knee flexion, and external rotation and ankle dorsiflexion, whereas standing serve produced a higher force-time integral in the rearfoot region. Different stepping angle and footwear friction could also influence the center of mass and kinematics of knee joint, respectively [27]. Different footwork imposed different lower limb kinematics requirements for table tennis players.

Table 2. Study characteristics of reviewed studies.

Author (Year)	Variant (s)	Maneuvers/Conditions	Type of Parameters
Bankosz and Winiarski (2017) [1]	Handwork (2) × power/serve (3)	Handwork: 1. Forehand crosscourt topspin 2. Backhand crosscourt topspin Handwork power and serve: a. Strength, speed and rotation of 75% max, against no-spin serve; b. Strength, speed and rotation of 75% max, against backspin serve; c. Strength and speed close to max, against no-spin serve;	Racket kinematics
Bankosz and Winiarski (2018) [2]	Handwork (2) × power/serve (3)	Handwork: 1. Forehand crosscourt topspin 2. Backhand crosscourt topspin Handwork power and serve: a. Force, velocity and rotation of 75%, against no-spin serve; b. Force, velocity and rotation of 75%, against backspin serve; c. Force, velocity close to max, against no-spin serve;	Racket kinematics, upper and lower limb kinematics
Bankosz and Winiarski (2018) [39]	Power/serve (3)	Forehand crosscourt topspin a. Force, velocity and rotation of 75%, against no-spin serve; b. Force, velocity and rotation of 75%, against backspin serve; c. Force, velocity close to max, against no-spin serve;	Racket kinematics, lower limb kinematics
Bankosz and Winiarski (2020) [33]	Serve (2)	Forehand crosscourt topspin 1. against a topspin ball 2. against a backspin ball	Upper limb, lower limb and trunk kinematics
Belli et al. (2019) [40]	Level (2)	Forehand or backhand offensive stroke chosen by players against backspin ball 100–120 cm from net and 30 cm away from either left or right side at 25 km/h with frequency of 54 balls per min	Ball speed, accuracy, performance index
Fu et al. (2016) [3]	Level (2)	Forehand crosscourt loop	PP
Ibrahim et al. (2020) [44]	Handwork (2)	1. Forehand drop shot 2. Long shot	Ball and racket kinematics, upper limb kinematics
Iino et al. (2008) [35]	Serve (2)	Backhand crosscourt loop 1. Against topspin serve 2. Against backspin serve	Ball kinematics, Upper limb kinematics
Iino and Kojima (2009) [24]	Level (2) × Serve (2)	Forehand crosscourt topspin as hard as possible 1. Against light backspin ball 2. Against heavy backspin ball	Ball and racket kinematics, trunk and upper limb kinematics
Iino and Kojima (2011) [25]	Level (2) × serve (2)	Forehand crosscourt topspin at max effort 1. Against light backspin ball 2. Against heavy backspin ball	Kinetics of upper limb
Iino and Kojima (2016) [26]	Racket mass (3) × ball frequency (2)	Backhand topspin at max effort Racket mass (153.5 g, 176 g, 201.5 g) Ball projection frequency (75 and 35 ball per minutes)	Racket kinematics, Upper limb and trunk kinematics and kinetics
Iino and Kojima (2016) [37]	Serve (2)	Backhand crosscourt topspin at max effort 1. Against topspin serve 2. Against backspin serve	Upper limb kinetics
Iino et al. (2017) [41]	Level (2)	Forehand crosscourt topspin 1. Intermediate players 2. Advanced players	Kinematics and variability of trunk, upper limb and racket kinematics
Iino (2018) [36]	Correlation study	Forehand crosscourt topspin at max effort	Racket kinematics/kinetics and pelvis kinetics

Table 2. *Cont.*

Author (Year)	Variant (s)	Maneuvers/Conditions	Type of Parameters
Lam et al. (2019) [4]	Footwork (3)	Forehand crosscourt topspin 1. One-step; 2. Side-step; 3. Cross-step	GRF, knee and ankle kinematics and kinetics, PP
LeMansec et al. (2016) [43]	Level (3)	Forehand crosscourt topspin 1. Inexperience players 2. Advanced players 3. Expert players	Ball speed and accuracy
LeMansec et al. (2018) [46]	Handwork (5)	1. Backhand top; 2. Flick (a close to net attack); 3. Forehand spin (topspin with more spin less power); 4. Forehand top (topspin with more power less spin); 5. Smash	Lower limb muscle EMG
Malagoli Lanzoni et al. (2018) [45]	Handwork (2)	1 Forehand longline topspin 2. Forehand crosscourt topspin	Racket, upper and lower limb kinematics
Meghdadi et al. (2019) [47]	Healthy vs. syndromic (2)	Forehand topspin loop	EMG, muscle onset and offset time
Qian et al. (2016) [28]	Level (2)	Forehand topspin loop	Lower limb kinematics and kinetics, PP
Shao et al. (2020) [34]	Level (2)	Forehand loop using a cross-step with maximal power against topspin	Lower limb kinematics, PP
Sheppardand Li (2007) [38]	Level (2)	1. Forehand return aimed for speed 2. Forehand returns aimed for speed with accuracy 3. Forehand returns aimed for accuracyNote: the three conditions were not independent factors of the study	Ball speed and accuracy, racket kinematics
Wang et al. (2018) [29]	Level (2)	Backhand crosscourt loop	Lower limb kinematics and kinetics, EMG
Yan et al. (2017) [27]	Footwork (2) × Footwear (3)	Footwork: 1. 180° step 2. 45° stepSole-ground friction: a. Low; b. Medium; c. High	CoM, Lower limb kinematics
Yu et al. (2018) [30]	Footwork (2)	Stroke NS 1. Stand serve 2. Squat serve	Lower limb kinematics and kinetics, PP
Yu et al. (2019) [48]	Footwork (2)	Forehand loop 1. Short chasse step 2. Long chasse step	Lower limb kinematics, EMG
Yu et al. (2019) [32]	Level (2)	Chasse step movement and forehand loop with maximal power against topspin	Foot kinematics, PP
Zhang et al. (2016) [31]	Level (2)	Forehand crosscourt stroke 1. Novice players 2. Expert players	Accuracy, Racket kinematics
Zhou (2014) [42]	Handwork (2)	1. Fast break 2. Curling ball	Racket speed

NS: not specified; CoM: centre of Mass; w/: with; w/o: without; PP: plantar pressure distribution; EMG: electromyography.

Comparing the lower limb biomechanics among players with various playing levels, Qian et al. [28] and Wang et al. [29] reported distinct findings for respective forehand and backhand crosscourt loops. When executing forehand topspin loop, higher-level players increased knee external rotation, hip flexion and decreased ankle dorsiflexion during backward end phase, and increased hip extension and internal rotation, decreased ankle and knee internal rotation during forward end phase. There was an overall increase in the ankle sagittal RoM as well as hip sagittal and coronal RoM [28]. When performing backhand crosscourt loop against backspin ball, higher-level players increased ankle dorsiflexion, eversion and external rotation, increased knee flexion and abduction and increased hip flexion, adduction, and external rotation at the beginning of backswing, as well as increased ankle dorsiflexion, knee flexion, reduced hip flexion but increased abduction at the end of swing [29]. During cross-step footwork, higher-level players executed superior foot motor control, as indicated by a smaller RoM of foot joints and higher relative load on the plantar toes, lateral forefoot and rearfoot regions [34]. They also demonstrated smaller forefoot plantarflexion and abduction during cross-step end phase but larger forefoot dorsiflexion and adduction during forward end phase [34]. Effective coordination of lower limb facilitates better upper body rotation in higher-level players [39].

Bańkosz and Winiarski [33] compared inter- and intra-individual variabilities of kinematic parameters. They reported that both variabilities could be quite high, but players attempted to minimize variability at critical moments, such as the instant of ball impact. Higher inter-individual variability could also imply that the technique of coordination movement is rather individual. Adopting or imitating a particular training regime has to pay more attention.

Plantar pressure was also used to evaluate foot loading among different playing levels. When performing forehand loop during backward end phase, higher-level players displayed larger plantar pressure excursion in the medial-lateral direction but smaller in the anterior-posterior direction, accompanied by increased contact areas at midfoot and rearfoot regions while decreased contact area at lesser toe region [3,28]. During forward end phase, higher-level and intermediate players decreased similarly the plantar pressure excursion in the anterior-posterior direction. The contact areas were increased at midfoot, rearfoot, and forefoot regions while decreased at the hallux region [3,28]. The change of plantar pressure excursion and contact area could reflect the strategy compromising dynamic stability and agility in different directions.

Table 3. Key findings of included studies comparing playing levels.

Author (Year)	Outcome Measures	Key Findings of Higher–Level Compared to Lower–Level Players
Belli et al. (2019) [40]	Ball speed; accuracy score, performance index (average speed × accuracy/100); percentage error for ball toward target zone	↑ Accuracy score; ↑ Performance index; ↓ Percentage error.
Fu et al. (2016) [3]	ML and AP excursion; Contact area for big toe, lesser toes, medial forefoot, lateral forefoot, midfoot and rearfoot	During backward end: ↑ ML excursion; ↓ AP excursion; ↑ Contact area for midfoot and rearfoot; ↓ Contact area for lesser toes; During forward end:↓ AP excursion; ↑ Contact area for midfoot, rearfoot, medial forefoot and lateral forefoot; ↓ Contact area for big toe
Iino and Kojima (2009) [24]	Ball speed before and after impact; Racket speed, face angle, path inclination and height at ball impact; Time required to reach 25% of racket speed at impact and max racket acceleration; Contributions to racket speed by: Max lower trunk axial rotation; mid hip linear; lower trunk lateral bending, flexion/extension, axial rotation; upper trunk axial rotation relative to lower trunk; shoulder linear relative to upper trunk; shoulder abduction, flexion, internal rotation; elbow flexion/extension; forearm supination/pronation; wrist palmar/dorsi flexion, radial/ulnar deviation	↑ Max racket acceleration; ↑ Contribution of lower trunk axial rotation to racket speed

Table 3. *Cont.*

Author (Year)	**Outcome Measures**	**Key Findings of Higher–Level Compared to Lower–Level Players**
Iino and Kojima (2011) [25]	Max joint torques of: shoulder adduction, flexion, internal rotation; elbow varus, flexion; wrist dorsiflexion and radial deviation; Max joint torque power of shoulder adduction, flexion, positive and negative internal rotation, elbow flexion, wrist dorsiflexion, and radial deviation; Net work done by shoulder adduction and internal rotation; Positive and negative work done by shoulder internal rotation torque; Max rate of energy transfer by: shoulder addiction and internal rotation; elbow varus and flexion; wrist radial deviation Amount of energy transfer by: shoulder adduction, flexion, internal rotation; elbow varus and flexion; wrist radial deviation; Max rate of energy transfer and amount of energy transfer through shoulder, elbow and wrist joints; Increase in mechanical energy of racket arm;Mechanical energy transferred to racket arm; Energy transfer ratio of racket arm.	↑ Normalized max joint torques of shoulder internal rotation, elbow varus, and wrist radial deviation; ↑ Max joint torque power of shoulder internal rotation in both positive and negative directions; ↑ Negative work done by shoulder internal rotation torque; ↑ Max rate of energy transfer for shoulder internal rotation, elbow varus and wrist radial deviation.
Iino et al. (2017) [41]	Racket speed at ball impact; Standard deviation of racket face angle in vertical and horizontal directions; Total, controlled and uncontrolled variable variance for racket race angle in vertical and horizontal directions; Ratio of uncontrolled to controlled variance	↑ Racket speed at ball impact; ↓ Controlled variance for horizontal angle of racket surface.
LeMansec et al. (2016) [43]	Ball speed; accuracy; performance index (average speed × accuracy/100)	Elite ↑ ball speed, accuracy and performance index than advanced players Advanced ↑ Ball speed, accuracy and performance index than inexperienced players.
Qian et al. (2016) [28]	Joint angle of ankle, knee and hip in all planes at backward-end (BE) and forward-end (FE); RoM of ankle, knee and hip joint in all planes.ACR of ankle, knee and hip in all planes during forward–swing phase; Contact area in big toe, other toes, medial and lateral forefoot, midfoot and rearfoot regions during BE and FE.	↑ Ankle RoM in sagittal plane; ↑ Hip RoM in sagittal and transverse planes; ↓ Knee RoM in sagittal plane. ↑ ACR of ankle and hip in all planes;During BE, ↑ Hip angle in sagittal plane; ↑ Knee angle in transverse plane; ↓ Contact area in other toes; ↑ Contact area in midfoot and rearfoot;During FE, ↑ Hip angle in sagittal (–) and transverse (–) planes; ↓ Knee angle in transverse (–) plane. ↓ Contact area in big toe; ↑ Contact area in medial and lateral forefoot, midfoot and rearfoot.

Table 3. *Cont.*

Author (Year)	Outcome Measures	Key Findings of Higher–Level Compared to Lower–Level Players
Shao et al. (2020) [34]	Duration for backswing phase, forward-swing phase and whole cycle;HTA, FTA in all planes and XFA in sagittal plane at BE and FE; RoM and ACR of HTA, FTA in all planes and XFA in sagittal plane at backswing phase;PP at backswing and forward-swing phases and relative load during entire motion of hallux, other toes, medial, central and lateral forefoot, medial and lateral midfoot, medial and lateral rearfoot regions	↓ Backswing phase but ↑ forward swing phase and total duration; ↓ FTA in sagittal (–) and transverse planes at BE; ↑ XFA in sagittal plane at BE;↓ HTA in frontal plane at FE; ↑ FTA in sagittal and transverse (–) planes but ↓ in frontal plane at FE; ↓ XFA in sagittal plane at FE;↓ RoM of HTA and FTA but ↑ XFA in sagittal plane at backswing phase; ↓ RoM of HTA in sagittal and frontal but ↑ in transverse plane at forward–swing; ↑ RoM of XFA in transverse plane at forward–swing;↑ ACR in all joints and planes at backswing phase; ↑ ACR in all joints and planes at forward–swing phase except HTA in frontal plane;↑ PP of lateral forefoot and medial rearfoot but ↓ lateral forefoot, central forefoot, medial forefoot, other toes, hallux at backswing phase;↑ PP if lateral rearfoot, lateral forefoot, other toes but ↓ central forefoot, hallux at forward swing phase; ↑ relative load of other toes, lateral forefoot, medial rearfoot, lateral rearfoot but ↓ hallux, medial forefoot
Sheppard and Li (2007) [38]	Frequency of successful returns, ball speed, ball bounce location accuracy; Racket speed, position, direction of motion, orientation; and Variability of racket speed, acceleration, horizontal and vertical direction of motions, orientation; at the −200, −150, −100, −50, 0, +50 ms relative to the moment of ball contact	↑ successful returns, ball speed, ball bounce location accuracy; Significant interaction between playing level and time on the overall ball kinematics variables (MANOVA) ↑ racket speed, rightward direction, downward oriented; ↓ variability on racket horizontal direction of motion and orientation
Wang et al. (2018) [29]	Hip, knee and ankle joint angles and ACRs in all planes at beginning of backswing and end of swing phases. Standardized average, mean power frequency and median frequency for EMG of rectus femoris and tibialis anterior for both limbs.	↑ Rate of angular change for knee and hip in all planes; ↑ Rate of angular change for ankle in sagittal but ↓ in horizontal; ↑ MPF mean power frequency for all muscles; At beginning of backswing ↑ Ankle dorsiflexion; eversion; external rotation; ↑ Knee flexion; abduction; ↑ Hip flexion, adduction and external rotation;At end of swing ↑ Ankle dorsiflexion; knee flexion; ↓ Hip flexion, ↑ abduction.

Table 3. *Cont.*

Author (Year)	Outcome Measures	Key Findings of Higher–Level Compared to Lower–Level Players
Yu et al. (2019) [32]	Duration for backswing phase, forward-swing phase and whole cycle; HTA, FTA in all planes and XFA in sagittal plane at backswing and forward-swing phases; RoM and ACR of HTA, FTA in all planes and XFA in sagittal plane at backswing and forward-swing phases; PP and relative load of hallux, other toes, medial, central and lateral forefoot, medial and lateral midfoot, medial and lateral rearfoot at backswing and forward-swing phases.	↓ Backswing phase but ↑ forward swing phase and total duration; ↓RoM of HTA, HFA in all planes ↑RoM of XFA in sagittal plane ↑ Relative load for other toes, lateral forefoot; ↓ Relative load for medial forefoot and medial rearfoot. During backswing phase, ↑ HTA in sagittal and transverse (–); ↓ HTA in frontal; ↓ FTA in all planes (–) ↑ XFA in sagittal (–); ↑ ACR of HTA in sagittal and frontal;↑ ACR of RTA in frontal;↓ ACR of XFA in sagittal ↑ Lateral forefoot, medial and lateral rearfoot; ↓ PP for hallux, medial and central forefoot; During forward-swing phase, ↑ HTA in sagittal and transverse (–); ↑ HFA in frontal and transverse; ↑ XFA in sagittal (–) ↑ ACR of FTA in y direction; ↑ PP for other toes, central and lateral forefoot; ↓ PP for hallux.
Zhang et al. (2016) [31]	Accuracy; Duration and variability of duration for each phase (preparatory, backswing, forward–swing, follow through)	↑ Accuracy; ↓ Variability of duration for forward-swing and follow through phases;

ACR: angular changing rate; AP: anteroposterior; BE: backward-end; EMG: electromyography; FE: forward-end; FTA: right forefoot to hindfoot angle; HTA: right hindfoot to tibia angle; ML: mediolateral; PP: peak pressure; RoM: range of motion; XFA: right hallux to forefoot angle. (–) in negative direction/value. The increase/decrease of (–) refer to the absolute magnitude; ↑: significantly higher/larger/increase; ↓: significantly lower/smaller/decrease.

4. Discussion

There was evidence suggesting that higher-level table tennis players produced higher ball accuracy, performance index, and trial-to-trial repeatability in both training and competition. Meanwhile, it was generally perceived that ball and racket velocities were deterministic to playing level since high velocities make the opponent difficult to return the ball. In particular, the maximum racket speed at the moment of impact was regarded as the most important playing technique [1]. However, the current evidence did not come into a consensus that higher-level players necessarily produce higher ball or racket speed. Shoulder joint seems to play an important role to coordinate an effective stroke, as indicated by the effective use of elbow flexion torque, while the power of wrist joint is important during drop shot or long shot services. On the other hand, lower extremities facilitated momentum generation for increased racket velocity. In fact, leg–hip–trunk kinetics accounted for more than half of the energy and muscle force generation in racket sports [28]. Apart from a shorter period of swinging time, the increase in hip flexion and knee external rotations for higher-level players would potentially facilitate a more efficient muscle output to maximize racket velocity through the kinetic chain [28,29], in addition to larger hip and ankle angular velocities [28] which could be correlated with an increased ball speed after ball impact [50]. It should be noted that body coordination movement varies across individuals and trials but players attempted to reproduce movement during critical instants [33]. This was known as functional variability such that players could adapt to the conditions and requirements of the tasks and compensated for the changes with other movement parameters [51]. An optimal training model of body movement could be different among athletes.

Techniques in footwork could play an important role in compromising between dynamic stability and agility to recover back to the ready position for next moves or strokes. Less experienced players tended to have a larger peak ankle dorsiflexion and anterior center of pressure but lesser contact area, which indicated a poorer support base and stability [3,28]. Additionally, a shorter center of pressure in the anterior–posterior direction in higher level players facilitates quicker responses to resume to a neutral position for the next move [3,28]. However, it should be noted that higher level players exhibited larger ankle RoM during the match which may inherit the risk of ankle sprain [28,29].

Regarding the methodological quality, more than half of the included studies did not reveal clearly the source of population and sampling method. There was also a lack of blinding. Although blinding the maneuver conditions seemed to be impossible since the participants needed to be acknowledged for the tasks they performed, it could be accomplished by counting successive returns from delivering random serves by the coaches or serving robots [30,40]. Furthermore, the implementation of a randomized cross-over design across various interventions and maneuvers is necessary to avoid carry-over effects. Future studies can investigate how technologies can improve training outcomes. For instance, augmented reality (AR) technology with different filmed footages of different balls and gaze information can be modulated with artificial intelligence program to simulate the virtual opponent with the matched playing levels. Such simulations would provide a steppingstone towards individualized training solutions. On the other hand, several studies investigated a large number of outcome variables which was not well justified. While a full biomechanical profile with a large number of outcome variables were endeavored, statistical analyses were performed without corrections for multiple or multivariate comparisons. This may fall into the trap of data dredging or p-hacking [52] and those research may confine to exploratory studies [53].

There are some limitations when interpreting our findings. A systematic scoping review covered a vast volume of literature over a topic and thus offered an overview picture within the discipline [21]. However, due to the heterogeneity and breadth of the included studies, the established data framework did not attempt to answer a single research question which shall be put forward by a systematic review. It is also not possible to conduct meta-analysis to estimate overall determinants on playing levels, movement tasks, and equipment because of the diversity of objectives and designs across the included studies. In fact, the amount of literature required for a subset study was insufficient to formulate a focused research question for a traditional systematic review. For example, only two included studies were comparing upper limb kinematics of forehand topspin among different player levels in our review. In other words, it is pragmatically demanding to call for more research to establish the map over biomechanical variables, maneuvers, and playing levels, and reinforce key ideas on the determinants of performance using a unified study design and protocol.

Additionally, there was potential publication or language bias since some relevant articles were excluded for being published in Chinese, despite the fact that China is one of the dominating countries in the table tennis sports [16]. Summarizing information from the Chinese literature can enhance the impact of table tennis research but may require considerable effort in screening, translation, and interpretation. Furthermore, we found that there was a lack of literature on backspin maneuvers, longline maneuvers, strikes against sidespin ball, and pen-hold players that warrant further investigations.

Table 4. Key findings of included studies comparing different movement tasks.

Author (Year)	Outcome Measures	Key Findings
Bankosz and Winiarski (2017) # [1]	Time parameters (total time, duration of forward, hit-to-forward end, backward phases, time to reach max velocity (resultant and direction components) of racket; Distance parameters (resultant and direction components of distance travelled by racket during whole cycle, forward, hit-to-forward end, backward phases); Velocity parameters of racket (resultant and direction components of mean, max and at impact).	Forehand stroke ↓ total duration than against a spin serve and more power ball. Backhand stroke ↓ total duration than against a spin Strokes with more power produced ↑ velocity and distance parameters in AP direction; strokes against spin produced ↑ velocity and distance parameters in vertical direction; Forehand stroke (against spin and more power), produced ↑ velocity and distance parameters than backhand stroke.
Bankosz and Winiarski (2018) # [2]	Max racket velocity, racket velocity at ball impact, time to reach max racket velocity, time to reach racket velocity at ball impact; Angular velocity (max, min, at impact) for wrist, elbow, shoulder, pelvis, hip, knee and ankle; Multiple regression on racket velocity and angular velocity parameters of body segments.	For maximum-effort forehand topspin, racket velocity was correlated with hip flexion velocity on playing side, hip extension velocity on opposite site, and ankle flexion velocity on playing side; For maximum-effort backhand stroke, racket velocity was correlated with shoulder joint angular velocities on playing side, flexion velocity of ankle and adduction velocity of hip on opposite side.
Bankosz and Winiarski (2018) # [39]	Racket speed at impact; RoM of ankle, knee, hip, wrist, elbow and elbow joints in all planes during forward, hit-to-forward end, backward phases.	Diff forehand topspin types produced different RoM; ↑shot power accompanied by ↑rotation of upper body, pelvis and shoulders, flexion and rotation in shoulder, elbows and knees.
Bankosz and Winiarski (2020) # [33]	Lumbar, chest, hips, knees, shoulders, elbows and wrists angles and inter-individual coefficient of variation at ready, backswing, contact and forward instants; Above data for exemplary players and intra-individual coefficient of variation; Acceleration of hand at contact instant.	↑ intra-individual variability and high range of inter-individual variability; ↑ variability was observed in abduction/adduction of hip joints, wrist joints, thoracic and lumbar spines; Slightly ↑ variability when hit against a backspin compared to that against a topspin; ↑ variability at ready instants than other instants;
Ibrahm et al. (2020) [44]	Horizontal velocity of ball and racket head; Mean angular velocity of shoulder, elbow and wrist joints; Correlation between horizontal velocity of ball and racket head, and body segmental angular velocity at impact.	In forehand drop shot, Ball horizontal velocity correlated with racket head horizontal velocity positively; Wrist radial deviation velocity positively correlated with horizontal ball and racket head velocity; In long shot, Wrist radial deviation velocity and palmar flexion angular velocity positively correlated with horizontal racket head velocity.
Iino et al. (2008) [35]	Ball speed before and after impact; Magnitude, direction components of upper arm flexion, abduction, external rotation, elbow extension, forearm supination, wrist ulnar deviation and dorsiflexion at impact; Contributions to forward and upward racket velocities.	Against topspin, compared to against backspin: ↑ Upward component of elbow extension (−); ↓ Upward component of wrist dorsiflexion; ↑ Contribution to racket upward velocity by elbow extension (−), ↓ wrist dorsiflexion and racket tip linear.
Iino and Kojima (2016) [26]	Racket speed, face angle and path inclination at ball impact; Racket trajectory length; Ball impact location; Max pelvis axial rotation velocity; Upper trunk axial rotation velocity relative to pelvis, shoulder flexion velocity, external rotation velocity, elbow extension velocity, wrist dorsiflexion velocity at impact; Peak torque for shoulder, elbow and wrist; Shoulder, elbow and wrist angular velocities at instants of their matching peak joint torque.	No significant interaction between racket mass and ball frequency on all variables.Higher ball frequency, compared to lower ball frequency: ↓ Racket speed at impact; significantly more forward impact location; ↓ Max pelvis axial rotation velocity, upper trunk axial rotation velocity relative to pelvis at impact; Large racket mass, compared to small racket mass: ↑ Peak wrist dorsiflexion torque.

Table 4. *Cont.*

Author (Year)	Outcome Measures	Key Findings
Iino and Kojima (2016) [37]	Racket resultant, horizontal and vertical velocity at impact; Max shoulder joint center velocity in rightward and upward; Max angular velocity of upper trunk in extension and axial rotation; Peak joint torque for shoulder, elbow and wrist; Torque work by shoulder and elbow; Amount of energy transfer by joint torque and force components; Energy transfer ratio of racket arm.	Against backspin, compared to against topspin ↑ Resultant and vertical; but ↓ horizontal racket velocity; ↑ Max shoulder center velocity in upward direction; ↑ Max angular velocity of upper trunk in both extension and axial rotation; ↑ Peak shoulder flexion, external rotation torque and elbow valgus torque; ↑ Torque work by shoulder flexion/extension; but ↓ shoulder internal rotation and elbow extension;↑ Energy transfer through shoulder joint in rightward, upward, flexion/extension torque, abduction torque; ↑ Sum of energy transferred through shoulder; ↑ Mechanical energy of racket arm; ↑ Energy transfer ratio of racket arm;
Iino (2018) [36]	Correlation coefficients with horizontal (hV) and vertical velocities (vV) of racket at impact on: peak pelvis angular velocities in axial rotation and backward tilt; lateral flexion, axial rotation and backward tilt of playing side hip and forward tilt of non-playing side hip;Torque and force of both hips; Posterior tilt torques and vertical forces at both hips;Axial rotation torques at both hips; Total work done on pelvis.	Peak pelvis angular velocity in axial rotation direction was significantly correlated with hV and vV (–); Forward tilt of non-playing side hip was significantly correlated with hV and vV (–); Axial rotation torque of playing side hip was significantly correlated with hV; Axial rotation torque of non-playing side hip was significantly correlated with hV and vV(–); Posterior tilt torques and vertical forces at both hips was significantly correlated vV; Axial rotation torques at both hips was significantly correlated with hV.
Lam et al. (2019) [4]	Max vGRF and hGRF; Max knee flexion angle and moment; Max ankle inversion angle, angular velocity and moment; PP; Pressure time integral for plantar regions: total foot, toe, 1st MT, 2nd MT, 3rd–4th MT, 5th MT, medial and lateral midfoot and heel.	One-step, compared to both side-step and cross step: ↓ Max hGRF and vGRF; ↓ Max knee flexion and moment; ↓ Max ankle inversion, angular velocity and moment. and max ankle inversion angular velocity; ↓ PP for total foot, toe, 1st MT, 2nd MT, 5th MT. Side-step, compared to cross-step only: ↓ Max hGRF and vGRF; ↓ Max knee flexion and max ankle inversion angular velocity; ↓ PP for total foot and 1st MT. One-step, compared to cross-step only: ↓ PP for medial midfoot, medial heel and lateral heel
LeMansec et al. (2018) [46]	EMG muscle activity level of vastus lateralis, vastus medialis, rectus femoris, soleus, gastrocnemius lateralis, gastrocnemius medialis, biceps femoris, gluteus maximus Global level (average level) of EMG for all muscles	Comparing 5 maneuvers: Backhand top (BT), flick (FL), forehand spin (FS), forehand top (FT), smash (SM): Global level of EMG BT ↑ all others; FL ↑ FS, FT, SM; FS↑ SM; For EMG of vastus lateralis and vastus medialis FS ↑ B, FL, SM; FT ↑ SM For rectus femorisFS and FT ↑ BT, FL, SM; For soleus and gastrocnemius lateralis BT ↓ FL, FT; SM ↑ all others For gastrocnemius medialis SM ↑ all others; FL ↑ BT, FS; FT ↑ BT, FS; For gluteus maximusFS, FT, SM ↑ BT, FL For biceps femoris FS, FT, SM ↑ BT, FL; FL ↑BT

Table 4. *Cont.*

Author (Year)	Outcome Measures	Key Findings
Malagoli Lanzoni et al. (2018) [45]	Angle of racket in all planes; Average feet-table angle; Max, min angle and moment of max velocity of racket (MMV) for angulation of: shoulders-table, shoulder-racket, pelvis-table, elbow and left/right knees	Cross-court, compared to long-line was: ↓ Racket angle in axial direction (z); ↓ Average feet-table angle; ↓ Max and min shoulder-table; ↓ Max but ↑ MMV of shoulder-racket angles; ↓ Max, min and MMV of pelvis-table angles; ↑ Elbow MMV; ↓ Right knee MMV
Meghdadi et al. (2019) [47]	Muscle activity; muscle onset; offset time instant for: supraspinatus, upper trapezius, lower trapezius, serratus anterior, biceps brachii, anterior deltoid	Shoulder impingement syndrome group, compared to healthy group ↓ muscle activity of supraspinatus and serratus anterior; ↑ muscle activity of upper trapezius; Significantly later muscle onset time for serratus anterior but significantly earlier muscle onset time for upper trapezius
Yan et al. (2017) [27]	Buffer time; CoM in AP and ML directions; Right knee angle at peak GRF	180° step compared to 45° step ↑ CoM in AP direction (A or P direction not specify); Higher sole-ground friction ↓ right knee angle at peak GRF.
Yu et al. (2018) [30]	Duration from initiation to backward-end, from backward-end (BE) to forward-end (FE), from forward-end to initial ready position (RP)Hip, knee and ankle angle at RP, BE and FE in three planes. Force-time integral in big toe, other toes, medial forefoot, lateral forefoot, midfoot and rearfoot	Squat serve, compared to standing serve: In sagittal plane ↑ hip angle at RP, BE and FE; ↑ knee angle at BE and FE; ↓ ankle angle at RP but ↑ at BE and FE; In frontal plane ↑ hip angle (–) at BE and FE; ↓ knee angle at BE and FE;In transverse plane ↑ hip angle at FE; ↑ knee angle at BE and FE; ↓ force-time integral in rearfoot
Yu et al. (2019) [48]	RoM of hip, knee and ankle joint in three planes. Hip, knee and ankle joint in three planes at take-off (T1) and backward-end (BE) instants. ACR of hip, knee ankle in three planes.	Long chasse steps, as compared to short chasse steps: ↑ RoM of hip in sagittal and transverse planes; ↑ RoM of knee in coronal plane; ↑ RoM of ankle in coronal and transverse planes; ↑ ACR of hip in sagittal plane; ↓ ACR of knee but ↑ that of ankle joint in coronal plane; ↑ ACR of hip and ankle in transverse plane; During T1, long chasse steps, compared to short chasse steps: ↓ hip angle in sagittal and transverse planes; ↓ knee angle in transverse plane; ↑ ankle angle in sagittal plane but ↓ in coronal and transverse planes (–); During BE, long chasse steps, compared to short chasse steps: ↓ hip angle in sagittal plane; ↑ knee angle in coronal plane but ↓ in transverse; ↑ ankle angle in sagittal plane
Zhou et al. (2014) [42]	Racket speed at ball contact, during backswing and follow through; percentage duration of backswing, attack and follow through phases	Curving ball, compared to fast break: ↑ racket speed at ball contact

ACR: angular changing rate; AP: anterior-posterior; BE: backward-end; CoM: center of mass; EMG: electromyography; FE: forward-end; hGRF: horizontal ground reaction force; hV: horizontal velocity; MMV: maximum velocity of the racket; MT: metatarsal; PP: peak pressure; RoM: Range of Motion; RP: ready position; T1: take-off; vGRF: vertical ground reaction force; vV: vertical velocity. (–) in negative direction/value. ↑: significantly higher/larger/increase; ↓: significantly lower/smaller/decrease of the absolute magnitude. # Only highlighted key findings were summarized in the table since these studies included too many outcome variables and/or pairwise comparison results to be listed.

5. Conclusions

A systematic scoping review of published studies specific to the biomechanics of table tennis maneuvers was conducted to categorize biomechanical variables within the domain of playing levels and maneuvers. This review could serve as the first scoping review to provide a clear overview about table tennis research in the past decades. Recent research on table tennis maneuvers targeted the differences between playing levels and between maneuvers using parameters which included ball and racket speed, joint kinematics and kinetics, electromyography, and plantar pressure distribution.

Different maneuvers underlined changes on body posture and lines of movement which were accommodated particularly by racket face angle, trunk rotation, knee and elbow joints, and different contributions of muscles. Key findings regarding determinants of playing levels were summarized to offer practical implications as follows:

- Higher-level players produced ball striking at higher accuracy and repeatability but not necessarily of higher speed.
- Strengthening shoulder and wrist muscles could enhance the speed of strike.
- Whole-body coordination and footwork were important to compromise between agility and stability for strike quality.
- Personalized training shall be considered since motor coordination and adaptation vary among individuals.

Moreover, this scoping review found that while most investigations focused on the upper and lower limb biomechanics of table tennis players performing different maneuvers, fewer studies looked into trunk kinematics and EMG. Furthermore, our study identified research gaps in backspin maneuvers and longline maneuvers, strikes against sidespin, and pen-hold players that warrant future investigations.

Author Contributions: Conceptualization, D.W.-C.W., and W.-K.L.; methodology, D.W.-C.W.; validation, W.C.-C.L.; formal analysis, D.W.-C.W., W.C.-C.L., and W.-K.L.; data curation, D.W.-C.W., and W.C-C.L.; writing–original draft preparation, D.W.-C.W.; writing–review and editing, W.C.-C.L. and W.-K.L.; visualization, D.W.-C.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: This is to declare that W.L.K. is an employee of Li Ning Sports Goods Company Limited. While the company sold table tennis rackets and garments, there is no direct connection and conflict of interest to this review article.

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