The kinematic analysis of the lower limb during topspin forehand loop between different level table tennis athletes

Yuqi He[1], Xiang Lyu[1], Dong Sun[1], Julien S. Baker[2] and Yaodong Gu[1]

[1] Faculty of Sports Science, Ningbo University, Ningbo, China
[2] Department of Sport, Physical Education and Health, Hong Kong Baptist University, Hong Kong, Hong Kong

Corresponding author
Yaodong Gu,
guyaodong@nbu.edu.cn

ABSTRACT

Background: Topspin is one of the most attacking stroke in table tennis sport. The aim of this research was to investigate the kinematic characteristics of the lower limb (driving leg) during topspin forehand loop in different playing level table tennis athletes.

Methods: Ten male table tennis athletes performed topspin forehand loop shots with maximal force to hit the ball that was played by a professional table tennis coach. The three-dimensional Vicon motion analysis system was used to capture the kinematic information.

Results: The key findings from this research indicate that there were no significant differences in motion time between elite athletes (EA) and medium athletes (MA) during the entire phase ($P = 0.784$). EA showed significantly less knee ($P < 0.001$) as well as hip ($P < 0.001$) flexion in the BS stage when contrasted to MA, with a significant larger ankle varus ($P = 0.003$) as well as eversion ($P < 0.001$) than MA in the BS and FS phase, respectively. EA displayed a significant larger angular changing rate of ankle dorsiflexion ($P < 0.001$) and varus ($P < 0.001$) in the BS stage with ankle plantar flexion as well as eversion during the FS stage, with a significant larger ankle internal rotation ($P = 0.003$) and external rotation ($P < 0.001$) than MA in the BS and FS phase, respectively. Furthermore, EA showed significantly larger ankle dorsiflexion ($P = 0.001$) as well as plantarflexion ($P < 0.001$) ROM in the BS and FS phase respectively compared with MA.

Conclusion: Ankle activities in the all plane displayed significant differences in kinematic characteristics between EA and MA. MA should pay attention to the function that ankle played in the kinetic chain, such as training the lower limb muscle rapid reaction ability to improve the energy transfer efficiency and capability of the kinetic chain.

INTRODUCTION

Table tennis sport as one of the most popular and important racket sport in the world, there are at least 40 million competitive table tennis players in 2016 (*Fuchs et al., 2018*). The characteristics of the fast rotation and high speed in the topspin forehand loop make

it become the most common and frequently used attacking technique in table tennis (*Poizat, Thouvarecq & Seve, 2004*). The topspin forehand loop was used frequently in table tennis winners compared with other types of stroke, and it is probably shows that mastery of this shot would make a critical effect to win matches (*Malagoli Lanzoni, Di Michele & Merni, 2014*). With the competition of table tennis becoming more and more intense, performing a better topspin forehand loop may influence the result of competitions. Mastering topspin forehand strokes could distinguish the performance of different level players even though it is difficult (*Iino & Kojima, 2009*).

Lower limbs played an important role to the performance during topspin forehand loop in racket sport, and the lower limb drive considerably influences ball and racket speed as the origin of the kinetic chain (*Qian et al., 2016*; *Elliott, 2006*; *Seeley et al., 2011*). A number of studies have investigated lower limb biomechanical contributions when playing table tennis and have analyzed details when using the topspin forehand loop. *Malagoli Lanzoni et al. (2018)* compared the kinematics of seven table tennis players using the long-line and cross-court topspin forehand loop. They mentioned a significantly larger flexion of the right knee at the moment of maximum racket velocity during the long-line. *Iino & Kojima (2009)* investigated the relation between different playing levels and kinematics information of racket during table tennis topspin stroke. They reported that high level players showed a significantly larger lower trunk rotation contribution to the racket speed at the moment of impact as well as a significantly larger maximum slope value in the speed-time curve of racket. They also tended to that the time for racket acceleration of advanced player was less than the intermediate players. *Qian et al. (2016)* compared biomechanics information of lower limbs between different level table tennis player during the forehand loop. They reported that compared with intermediate players. The superior players showed a significantly larger external rotation of the knee joint as well as flexion of the hip joint in the backward-end, and a significantly larger hip internal rotation and extension was showed at the forward-end. The above research shows that, investigations into the lower limbs biomechanical characteristics during the topspin stroke are crucial and necessary.

As one of the most offensive table tennis stroke, topspin forehand is extremely important for an aggressive player to master this shot properly (*Iino & Kojima, 2009*). *Iino & Kojima (2009)* reported the biomechanical analysis during topspin forehand loop against backspin balls between different level table tennis players. They reported values for the kinematic analysis of lower trunk flexion, rotation, and extension. Two group male table tennis players that include nine advanced and eight intermediate hit topspin forehands to against heavy and light backspins. However, the ankle, hip and knee kinematics in the frontal, sagittal and transverse planes were not investigated in their research. Hence, he aim of this research was to show the knee, hip and ankle joint kinematic characteristics in sagittal, frontal and transverse plane during a set of topspin forehand loop hits in different playing level table tennis players. The motion time, ROM, angular changing rate and joint angle of the lower limb in sagittal, frontal and transverse plane were measured and analysis in this research. From a practical point of view, this research would provide useful information in the modulation of body motion

Table 1 The information of the participant (Mean ± SD).

Population	Level	Height (cm)	Weight (kg)	Handedness	Experience (year)
5	EA	173 ± 4.2	70 ± 7.9	Right	10 ± 3
5	MA	172 ± 2.7	69 ± 8.5	Right	9 ± 3

requirements to table tennis athlete. Previous studies have described the torsional mechanism of topspin hitting in table tennis players at different levels. However, as the part of lower limb kinetic chain, the mechanism and differences of lower limb joints have not been studied in detail, the hypothesis of this research was that the lower limb especially driving leg as the basic section of power chain will prevent a significant difference between two different level table tennis athletes.

METHODS

Participants

As outlined in Table 1. Ten professional male table tennis athletes were allowed to participate in this study. All of the participate was attached to the table tennis team at Ningbo University, Ningbo China. The group of participant was divided into two groups: Five players (Height: 173 ± 4.2 cm, Weight: 70 ± 7.9 kg, Experience: 10 ± 3 years) were belong to elite athletes (EA) who play in the China National Level I. Another five players (Height: 172 ± 2.7 cm, Weight: 69 ± 8.5 kg, Experience: 9 ± 3 years) were belong to medium athletes (MA) who play in China National Level II. All participants were right-handed and nobody with previous diseases or deformity of the lower limb for 3 months before this study. The handedness of the athletes was identified and confirmed based on the preferential hand used to hold the racket. Caffeine was forbidden to ingestion of all participant for 4 h before this study. Before the commencement of this research, participants were provided to write informed consent. This research was approved by the Ethics Committee of Research Academy of Grand Health at Ningbo University (RAGH20191121).

Experimental procedures

As outlined in Fig. 1. Data were collected as previously described in *Qian et al. (2016)* and *Wang et al. (2018)*. The kinematic information with participant was captured by an 8-camera Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK) at a 100 Hz frequency. A total of 16 reflective markers (diameter: 14 mm) were attached with adhesive tape on the bilateral lower limbs respectively. Marker locations included: posterior-superior iliac spine, anterior superior iliac spine, lateral mid-thigh, lateral knee, lateral malleolus, lateral mid-shank, second metatarsal head, and calcaneus.

Players were asked to perform only the forehand topspin loop with maximal power to return the topspin ball played from a professional table tennis coach to the target area (A: L1 = 45 cm, L2 = 38 cm). If the ball was missed or outside of the target area (A), the action will not be measured, and participants need to do it again. The coach was asked to keep a stable ball track and drop point, the speed and frequency of the ball was also
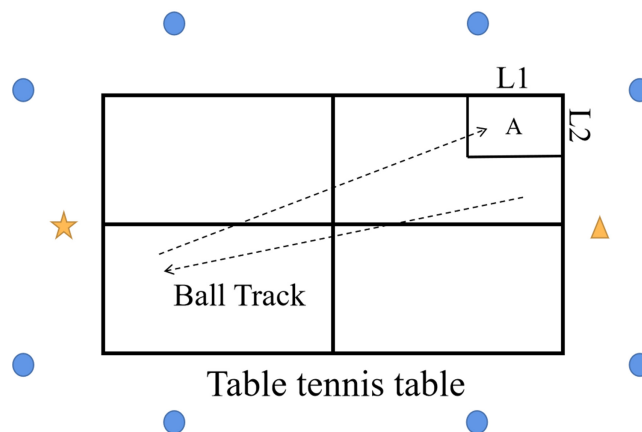
Figure 1 Experiment setup. L1: 45 cm, L2: 38 cm, A: Target area, ☆: Participant, Δ: Coach, ○: Camera.

controlled by the coach. The action of the players was recorded until three full motions were successfully captured. And participant was allowed adjustment or rests 1 min between actions. In addition, all players were given at least 15 min to warm up and adaption the experimental environment before the commencement of the official experiment and data collection.

Segmental coordinate systems
The segmental coordinate systems were created as previously described in *Iino & Kojima (2009)*.

Lower trunk
The vector that from the middle point on both sides of the hip joint centers to the middle point on both side of shoulder joint centers was defined as the z-axis of the lower trunk coordinate system. The X-axis was defined as the cross product of the vector from the center of the right hip to the center of the left hip with the z-axis. The cross product of the z-axis and x-axis was defined as y-axis.

Driving leg
The z-axis of the driving leg (right leg) was same as the lower trunk z-axis. The y-axis was the cross product of the z-axis of the system and a vector from the ankle joint center to the knee joint center. The cross product of the y- and z-axis was defined as x-axis.

Ankle
The y-axis of the ankle coordinate system was a vector from the head of the third phalangeal to the center of the ankle joint. The x-axis was a vector from the first phalanx medial to the fifth phalanx lateral. The z-axis was the cross product of the z- and x-axes of the ankle.

Experimental material
The location of the experiment was at Ningbo University table tennis training Centre, which is a professional competition and training facility. During the experiment, players
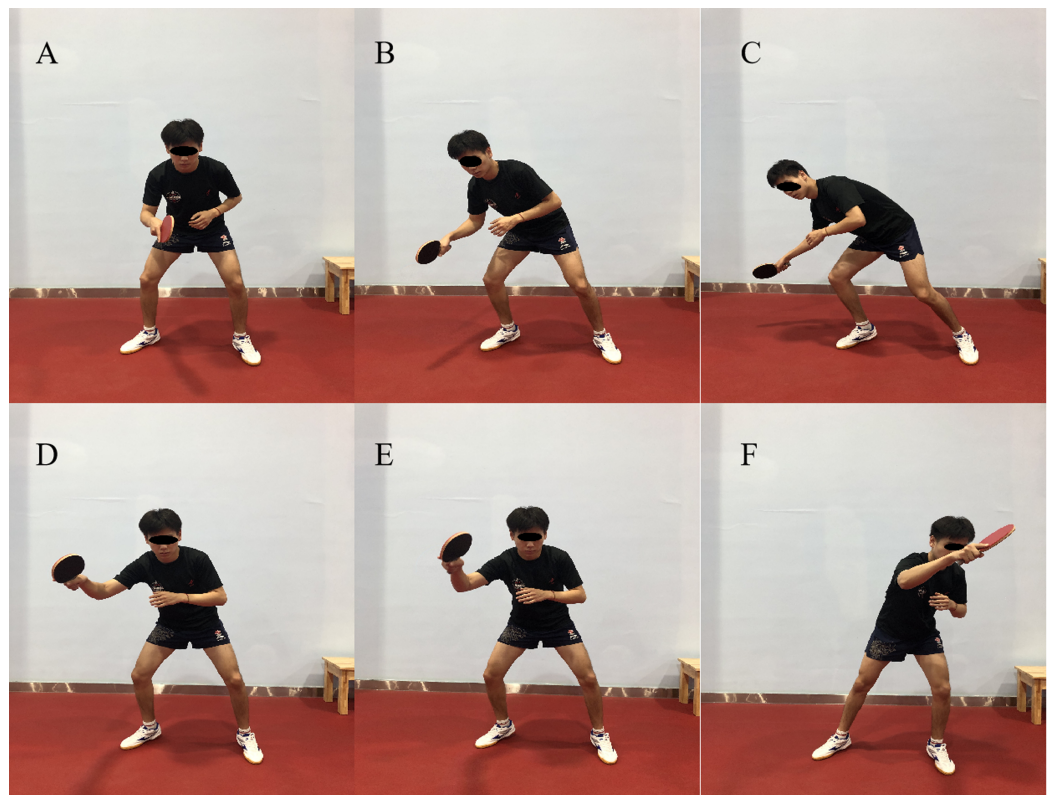
Figure 2 The divide and definition of motion phase. Motion phase A was defined as a natural position (NP), (A–C) was defined as the backswing phase (BS), (D–F) was defined as the forward swing phase (FS). Position C was defined as the key event which meant the end of the backswing phase (EB). Position F was defined as the key event which meant the end of the forward swing phase (EF).

were asked to wear professional table tennis matches shoes. Besides, whole of the player was asked to use the same table tennis racket (Timoboll-zlc; Butterfly Technical Center, Tokyo, Japan) with the Butterfly Tenergy 05 Max (Butterfly Technical Center, Tokyo, Japan) and DHC Hurricane 3 (Double Happiness Sports Company, Shanghai, China) rubber sheets. The DHC Hurricane 3 rubber was the forehand side one. And the playing table used for data capture (Rainbow; Double Happiness Sports Company, Shanghai, China) was a professional game table.

Definition motion phase

As outlined in Fig. 2. Motion phase A was defined as a natural position (NP). Figures 2A–2C was defined as the backswing phase (BS), Figs. 2D–2F was defined as the forward swing phase (FS). Besides, this research focus on the key event of the entire motion, so we defined the position C as the key event which meant the end of the backswing phase (EB). And the position F was defined as the key event which means the end moment of the stage of the forward swing (EF).

Table 2 Comparison of time at the phase of BS and FS between EA and MA (unit: second).

Variables	EA Mean ± SD	MA Mean ± SD	P-Value
BS phase	0.39 ± 0.06	0.45 ± 0.05	0.004*
FS phase	0.57 ± 0.07	0.52 ± 0.06	0.038*
Entire phase	0.96 ± 0.09	0.97 ± 0.09	0.784

Notes:
* A significant difference at the EA and MA.
BS, backward-swing; FS, forward-swing; EA, elite athlete; MA, medium athlete.

Table 3 Comparison of joints angles at key events between EA and MA (unit: degrees).

Variables	ANKLE		KNEE		HIP	
	BE Mean ± SD	FE Mean ± SD	BE Mean ± SD	FE Mean ± SD	BE Mean ± SD	FE Mean ± SD
X (EA)	15.77 ± 5.12*	15.96 ± 13.52	41.15 ± 8.83*	42.50 ± 22.52	48.31 ± 2.13*	2.00 ± 11.29*
X (MA)	12.34 ± 3.27*	22.13 ± 2.37	58.80 ± 2.29*	47.86 ± 5.00	66.48 ± 1.77*	23.35 ± 2.28*
Y (EA)	4.85 ± 3.78*	17.42 ± 3.59*	14.74 ± 2.86*	20.73 ± 3.28*	−10.64 ± 3.12	−26.05 ± 7.36*
Y (MA)	1.55 ± 0.97*	8.74 ± 1.31*	30.18 ± 2.12*	36.01 ± 2.14*	−11.88 ± 2.18	−34.07 ± 2.45*
Z (EA)	−25.25 ± 16.53*	−50.60 ± 8.36*	18.86 ± 5.94*	13.61 ± 1.96*	23.60 ± 6.41*	11.37 ± 1.41*
Z (MA)	−10.74 ± 3.70*	−33.67 ± 2.82*	10.96 ± 1.33*	−0.10 ± 2.20*	34.18 ± 1.13*	16.40 ± 1.18*

Notes:
* A significant difference at the hip, knee, and ankle (respectively) ($P < 0.05$)
X, the sagittal plane; Y, the frontal plane; Z, the transverse plane. BE, backward-end; FE, forward-end; EA, elite athlete; MA, medium athlete.

Statistical analysis

Statistical analysis and calculation were used by SPSS 19.0 version software (SPSS Inc., Chicago, IL, USA). The normal distribution of variables was verified using the Shapiro-Wilks normality test. As the driven leg, the right leg kinematic differences in the topspin forehand loop between the two levels of players were examined by independent T-tests. The Analysis included joint angles, motion time, angular changing rate and ROM of the ankle, knee, and hip joint. The significance level was set at $P < 0.05$.

RESULTS

Motion time

As outlined in Table 2. The time taken to perform a topspin loop was 0.96 ± 0.09 s and 0.97 ± 0.09 s for EA and MA, respectively. EA demonstrated significantly less time than MA in the BS stage (t-value = −3.097, $P = 0.004$), however, EA showed a significantly larger time in the FS phase (t-value = 2.180, $P = 0.038$). Moreover, there were no significant differences in the time during the entire stage between EA and MA (t-value = −0.277, $P = 0.784$).

Lower-limb joint angle

Table 3 and Fig. 3 showed the angles of joint at BE as well as FE in the transverse, frontal, as well as sagittal planes for both EA with MA. In the frontal plane as well as the transverse
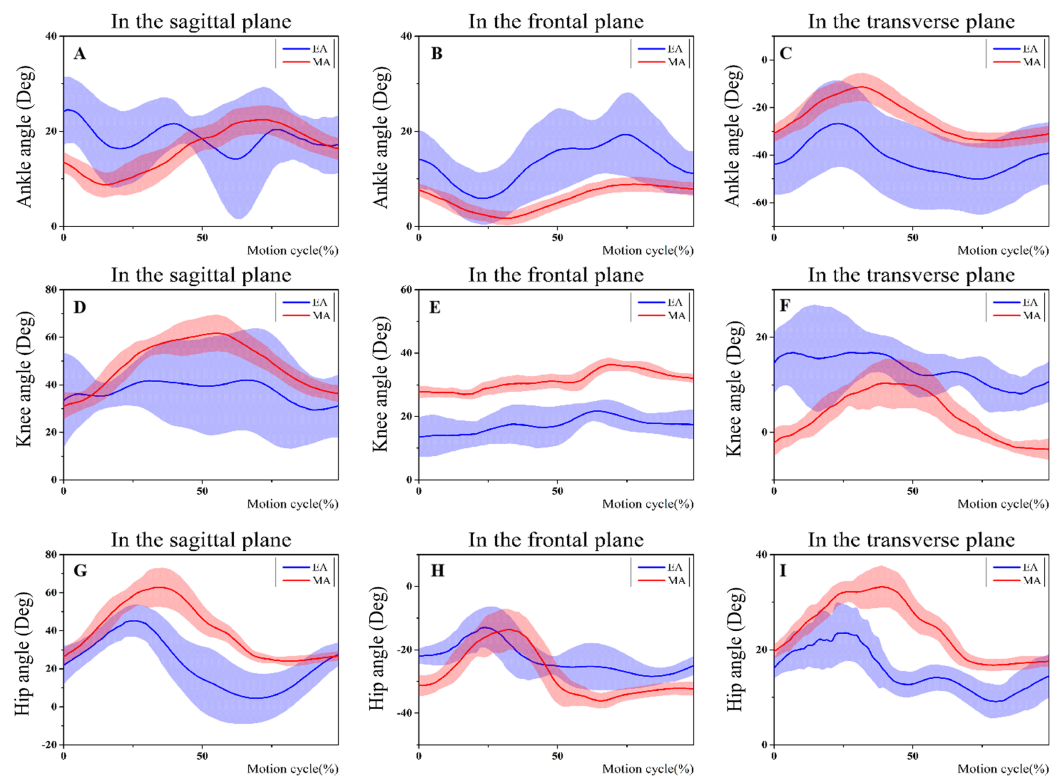
Figure 3 Changes of the lower limb joints angle during the entire phase in three planes. (A–C) Ankle angle changes during the entire phase in three planes; (D–F) knee angle changes during the entire phase in three planes; (G–I) Hip angle changes during the entire phase in three planes.

plane, EA displays significant differences of joint angles for the entire stage compared with the MA. In the sagittal plane, EA showed significantly less knee (t-value = −7.496, $P < 0.001$) and hip (t-value = −25.397, $P < 0.001$) flexion in the BE phase compared with MA. In the frontal plane, EA showed a significantly larger ankle varus (t-value = 3.282, $P = 0.003$) and eversion (t-value = 8.799, $P < 0.001$) than MA in the BE and FE phases, respectively. Moreover, in the transverse plane, EA displayed a significantly larger ankle internal rotation (t-value = −3.320, $P = 0.003$) and external rotation (t-value = −7.428, $P < 0.001$) than MA in the BE and FE phase, respectively. EA showed a significantly larger knee external rotation (t-value = 5.027, $P < 0.001$) and internal rotation (t-value = 19.219, $P < 0.001$) in the BE and FE phase respectively compared with MA. However, MA showed a significantly larger hip external rotation (t-value = −6.299, $P < 0.001$) and internal rotation (t-value = −10.590, $P < 0.001$) in the BE and FE phase respectively compared with EA.

Range of motion

ROM at BS as well as FS stage between EA and MA in all planes have displayed at the Table 4 as well as Fig. 4. Lower-limb ROM showed significant differences during the BS as well as FS phases between EA and MA. Compared with MA, EA showed significantly larger ankle dorsiflexion (t-value = 3.838, $P = 0.001$) and plantarflexion (t-value = 4.792,

Table 4 Comparison of ROM at the phase of BS and FS between EA and MA (unit: degrees).

Variables	ANKLE		KNEE		HIP	
	BS Mean ± SD	FS Mean ± SD	BS Mean ± SD	FS Mean ± SD	BS Mean ± SD	FS Mean ± SD
X (EA)	11.50 ± 3.76*	19.66 ± 6.31*	16.02 ± 5.62*	14.48 ± 4.25	25.01 ± 9.10*	44.93 ± 10.52
X (MA)	7.23 ± 2.11*	10.95 ± 3.13*	28.16 ± 5.92*	16.31 ± 4.79	39.94 ± 3.92*	42.90 ± 2.32
Y (EA)	9.78 ± 3.08*	15.36 ± 3.47*	5.90 ± 1.28*	8.44 ± 1.80	12.00 ± 2.47*	20.44 ± 4.45*
Y (MA)	6.60 ± 1.06*	7.22 ± 1.03*	4.65 ± 1.28*	15.36 ± 3.47	20.43 ± 2.40*	24.90 ± 2.51*
Z (EA)	20.52 ± 5.77	27.05 ± 6.66*	12.54 ± 3.37	11.67 ± 6.25	8.11 ± 6.23*	13.74 ± 7.51*
Z (MA)	21.73 ± 3.31	22.75 ± 3.20*	13.34 ± 2.91	13.37 ± 2.40	15.16 ± 1.80*	19.45 ± 1.14*

Notes:
X, the sagittal plane; Y, the frontal plane; Z, the transverse plane. BS, backward-swing phase; FS, forward-swing phase; EA, elite athlete; MA, medium athlete.
* A significant difference at the hip, knee, and ankle (respectively) ($P < 0.05$).
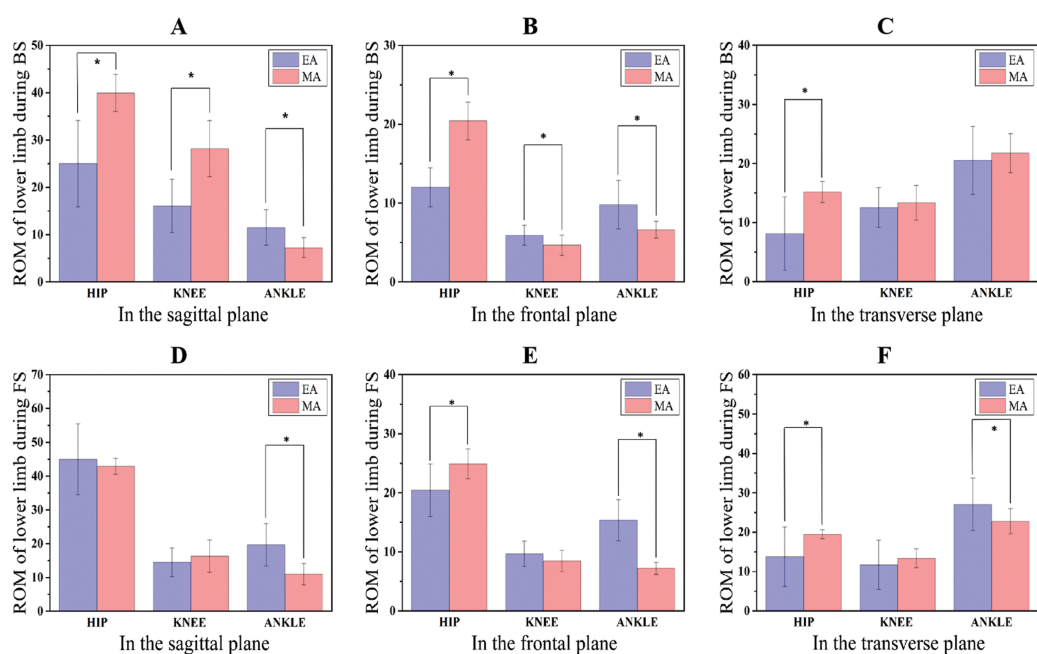
Figure 4 Changes of lower limb ROM during BS and FS phase in three planes. (A–C) Lower limb ROM changes during BS in three planes; (D–F) lower limb ROM changes during FS in three planes.

$P < 0.001$) ROM in the BE and FE phase respectively. Moreover, EA showed a significantly larger ankle varus (t-value = 3.788, $P = 0.001$) and external rotation (t-value = 2.251, $P = 0.032$) ROM in the BE and FE phase respectively. However, EA showed significantly less hip flexion (t-value = −5.836, $P < 0.001$) and external rotation (t-value = −4.211, $P < 0.001$) ROM in the BE phase contrast with MA.

Angular changing rate

Angular changing rates at BS as well as FS phases between EA and MA in all planes were shown at Table 5 as well as Fig. 5. In the stage of BS and FS, both in the sagittal and

Table 5 Comparison of the angular changing rate at the phase of BS and FS between EA and MA (unit: degrees/second).

Variables	ANKLE		KNEE		HIP	
	BS Mean ± SD	FS Mean ± SD	BS Mean ± SD	FS Mean ± SD	BS Mean ± SD	FS Mean ± SD
X (EA)	34.01 ± 11.80*	30.98 ± 8.48*	37.56 ± 10.15*	25.06 ± 5.68*	55.02 ± 19.10*	72.26 ± 14.85
X (MA)	15.09 ± 4.98*	21.81 ± 8.05*	59.60 ± 11.30*	31.44 ± 6.71*	89.62 ± 8.79*	77.66 ± 12.90
Y (EA)	23.74 ± 9.93*	26.22 ± 4.61*	15.89 ± 4.64*	16.22 ± 5.23	33.84 ± 7.70*	34.07 ± 9.74*
Y (MA)	14.86 ± 2.08*	13.70 ± 2.21*	10.99 ± 3.33*	16.50 ± 4.47	46.23 ± 8.57*	46.70 ± 9.04*
Z (EA)	55.99 ± 16.37	47.63 ± 13.89	31.03 ± 5.63	18.66 ± 8.91*	10.46 ± 15.21*	15.97 ± 11.52*
Z (MA)	46.39 ± 7.50	43.07 ± 8.23	28.81 ± 4.93	25.73 ± 4.15*	34.19 ± 3.32*	35.53 ± 5.44*

Notes:
* A significant difference at the hip, knee, and ankle (respectively) ($P < 0.05$).
X, the sagittal plane; Y, the frontal plane; Z, the transverse plane. BE, backward-swing phase; FE, forward-swing phase; EA, elite athlete; MA, medium athlete.
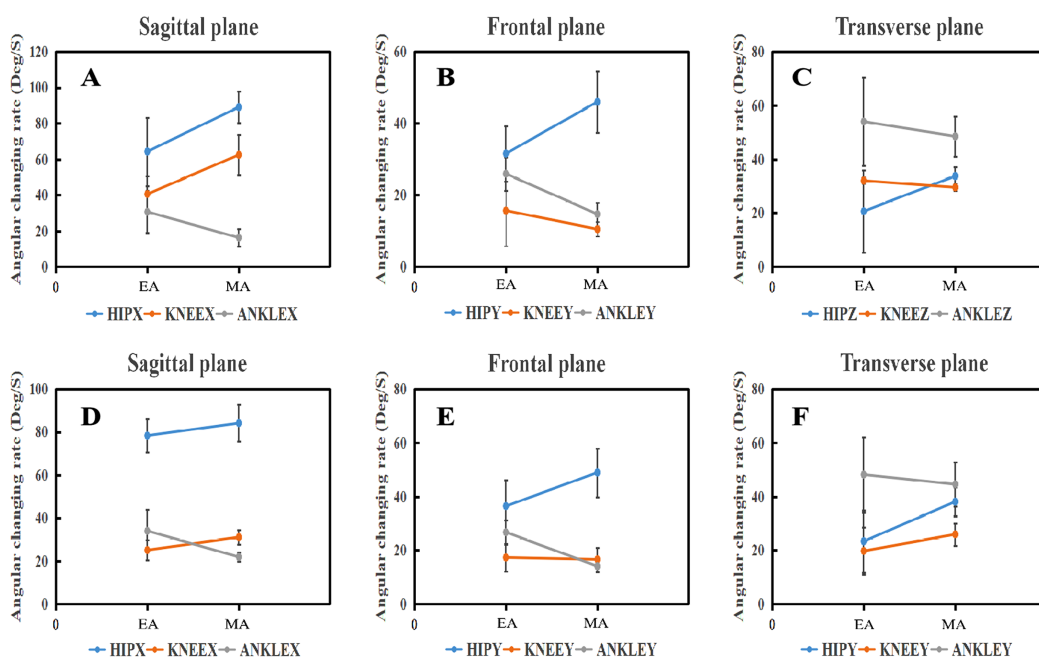
Figure 5 Angular changing rate of lower limb joints during BS and FS phase in three planes. The top is the BS phase, Bottom is the FS phase. (A–C) Angular changing rate of lower limb during BS phase in three planes; (D–F) angular changing rate of lower limb during FS phase in three planes.

frontal plane, the angular changing rate of ankle joint for the EA was significantly larger than MA. However, EA showed a significantly smaller angular changing rate in the hip (t-value = −4.572, $P < 0.001$) and knee (t-value = −5.592, $P < 0.001$) joint during BS in the sagittal plane.

DISCUSSION

The aim of the research was to describe and compare the lower limb kinematic characteristics of the topspin forehand loop between EA and MA. The key findings of this

study were: In time-spending, have no significant differences between EA as well as MA during the entire playing phases. (1) EA showed a significantly less knee and hip flexion in the BS stage compared with MA, and a significantly larger ankle varus and eversion than MA in the BS and FS phases, respectively. (2) EA displayed a significantly larger angular changing rate in ankle dorsiflexion as well as varus during the BS phase with ankle plantarflexion and eversion during the FS phase. Moreover, EA showed a significantly larger ankle internal and external rotation than MA in the BS and FS phases, respectively. (3) Compared with MA, EA showed a significantly larger rotation of external as well as internal in the knee in the BS and FS stage respectively. EA showed significantly larger ankle dorsiflexion and plantarflexion ROM in the BS and FS phases respectively compared with MA.

Between EA and MA during the entire phase, have no differences in motion time for significant. However, significantly less time was showed by EA during the BS phase as well as a significantly larger time period during FS compared with MA. *Bankosz & Winiarski (2017)* reported that increasing the BS phase resulted in longer subsequent phases and elongation of the total time. However, *Qian et al. (2016)* reported that compared with intermediate players, the superior players showed less time during FS.

Elite athletes showed a significantly larger ankle varus and internal rotation than MA in the BS stage. This could reinforce the stretching activity of internal rotation, and resulting in the contraction effects enhanced during the FS phase (*Zhang et al., 2017*). According to the theory of stretch-shortening cycle, performance of concentric contraction of muscle tendons would be enhanced by the elastic energy stored in the process of eccentric (*Elliott, 2006*; *Walshe, Wilson & Ettema, 1998*). This means that EA makes a greater preparation of the ankle during BS compared with MA. Compared with MA, EA showed significantly less knee and hip flexion in the BS phase, as well as a significantly larger ankle varus and internal rotation in the BS phase. This probably indicates the compensatory mechanism of the ankle joint in the BS phase. Excessive flexion of the hip and knee joint may result in the next lower limb stretching action initial speed to decrease. More sufficient torsion of the ankle joint can compensate for the flexion of the knee and hip joint, which is helpful to improve the flexibility of the lower limbs. In fact, a way that a high racquet speed could generate on impact without undue injury risk was must coordinate in the all kinetic chain links (*Elliott, Grove & Gibson, 1988*; *Elliott, 2006*).

In the stage of FS, EA showed a significantly larger ankle external rotation and eversion than MA. Moreover, EA displayed a significantly larger external rotation and internal rotation of the knee in the BS and FS phases respectively compared with MA. This may result in a greater transfer range of weight to promote momentum generation (*Ball & Best, 2007*). Advanced players exhibited more whole-body movements than lower-skilled players by rotating the upper body through effective use of the knee joints that in the previous table tennis studies on lower-limb biomechanics (*Bankosz & Winiarski, 2018a*). *Myers et al. (2008)* reported that increased rotational counter movement of torso and pelvic at the top of downswing in golf was associated with increased ball velocity. Compared with MA, EA showed a more sufficient ankle eversion rotation in the FS phase,

and EA more sufficient ankle pedaling and stretching probably means a faster weight transfer effect. *Bankosz & Winiarski (2018b)* have reported that involved segments of the lower limbs support proximal-to-distal movement sequencing: plantarflexion and rotation of the ankle joint, and rotation in the knee and hip joints. These movements result in the upward and forward velocity of the whole playing upper limb increased at the contact moment during the follow-through movement. Moreover, *Kasai & Mori (1998)* have evaluated the technique and performance of topspin shots. They drew attention to the differences between players, depending on the performance level. Players with a high-performance level had significant cooperation from the whole body, specifically the rotation of the trunk and the work of the knee joints. According to kinetic chain perspectives, the speed of racket and ball in racket sport considerably influenced by the energy transferred from lower-limb to the upper limbs (*Lam et al., 2018*; *Reid, Elliott & Alderson, 2008*). An important factor related to optimizing energy transfer in the kinetic chain is joint angular velocity which is expected to increase as skill levels improve (*Seeley et al., 2011*). Another key finding from this study is that EA displayed a significantly larger ankle dorsiflexion and varus changing rate during the BS phase with ankle plantarflexion and eversion during the FS phase. *Qian et al. (2016)* have reported a similar result. This finding further reveals that the ankle joint as the starting point of movement plays an important role in topspin forehand loop. The increased ankle angular changing rate of EA during FS in this study may be related to a more effective lower limb drive the ball speed to increase (*Qian et al., 2016*). The quality of whiplash-like action was assessed by the sequence as well as interval of time in momentum transfer between the distal and proximal (*Kibler & Van der Meer, 2001*). The higher angular changing rate of the ankle probably means compared with MA, EA displayed a faster weight transfer and a shorter time of pedal and stretch in the lower limb. This proximal segments power transference may play a crucial role of throwing speed, such as the ability that mechanical energy transmits from the trunk to the upper limb to produce a faster racket speed in the athletes (*Zemkova, Muyor & Jelen, 2018*). *Wang et al. (2018)* have reported the similar point, in their study, EA presented a larger angular changing rate of lower limb joint, and less time to hit the table tennis ball, that probably means a higher speed of play. *Seeley et al. (2011)* revealed that the speed of post-impact increased from slow to medium levels results in the velocity of peak ankle plantarflexion and hip extension increased in racket sport forehand. However, during the forehand topspin, the larger knee and ankle loading magnitudes found in sidestep and cross-step footwork would predispose to overuse conditions of table tennis players such as jumper knee (*Lam et al., 2018*; *Rajabi et al., 2012*) and ankle sprain injuries (*Lam et al., 2018*; *Fong et al., 2009*). This requires to development the ability of rapid muscle response to stabilize dynamic joint during sport activities (*Cerqueira et al., 2020*). We can speculate that a focus on the rapid response ability of the muscles that surrounding the ankle joint will effectively enhance the ankle dynamic stability as well as decrease the injury likelihood in the ankle during the fast movement of table tennis topspin forehand loop play. This information will guide coaches and athletes to attach importance to the role of

the ankle joint in the lower limb dynamic chain in the forehand topspin, and the training of the lower limb muscle rapid reaction ability, especially the ankle joint.

There are some limitations to this study that should be mentioned. One of the major limitations of this study was that the athletes performed the action without a match environment. Besides, during the moment of racket-ball impact, there are no variables information in this study.

CONCLUSION

The forehand technique between EA and MA athletes in the lower limb kinematics was investigated with quantitative analysis in this research. It comprehensively shows the lower limb kinematic characteristics and differences between EA and MA athletes in table tennis topspin techniques. The activity of ankle in the plane of sagittal, frontal and transverse displayed the most significant differences in kinematic characteristics between EA and MA. Besides, MA should pay full focus on the function that ankle played in the kinetic chain. This will improve the energy transfer efficiency and capability of the kinetic chain. The findings of this study can provide information about improved topspin technical for coaches and athletes.

Funding
This work was supported by the National Natural Science Foundation of China (No. 81772423), and the K. C. Wong Magna Fund in Ningbo University. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures
The following grant information was disclosed by the authors:
National Natural Science Foundation of China: 81772423.
Ningbo University.

Competing Interests
The authors declare that they have no competing interests.

Author Contributions
- Yuqi He conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Xiang Lyu conceived and designed the experiments, performed the experiments, prepared figures and/or tables, and approved the final draft.
- Dong Sun performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Julien S. Baker analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

• Yaodong Gu conceived and designed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The Ethics Committee of Research Academy of Grand Health at Ningbo University (RAGH20191121) granted approval to carry out the study.

Data Availability

Raw measurements are available in Supplemental Files.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.10841#supplemental-information.

REFERENCES

Ball K, Best R. 2007. Different center of pressure patterns within the golf stroke II: group-based analysis. *Journal of Sports Sciences* **25(7)**:771–779 DOI 10.1080/02640410600875002.

Bankosz Z, Winiarski S. 2017. The kinematics of table tennis racquet: differences between topspin strokes. *Journal of Sports Medicine and Physical Fitness* **57(3)**:202–213.

Bankosz Z, Winiarski S. 2018a. Correlations between angular velocities in selected joints and velocity of table tennis racket during topspin forehand and backhand. *Journal of Sports Science and Medicine* **17(2)**:330–338.

Bankosz Z, Winiarski S. 2018b. The evaluation of changes of angles in selected joints during topspin forehand in table tennis. *Motor Control* **22(3)**:314–337 DOI 10.1123/mc.2017-0057.

Cerqueira ASO, Soares RJ, Corrêa RAA, Mezêncio B, Amadio AC, Serrão JC. 2020. Muscle stretching changes neuromuscular function involved in ankle stability. *Physiotherapy Theory and Practice* **36(10)**:1130–1136 DOI 10.1080/09593985.2018.1548046.

Elliott B, Grove JR, Gibson B. 1988. Timing of the lower limb drive and throwing limb movement in baseball pitching. *Journal of Applied Biomechanics* **4(1)**:59–67 DOI 10.1123/ijsb.4.1.59.

Elliott B. 2006. Biomechanics and tennis. *British Journal of Sports Medicine* **40(5)**:392–396 DOI 10.1136/bjsm.2005.023150.

Fong DT, Hong Y, Shima Y, Krosshaug T, Yung PS, Chan KM. 2009. Biomechanics of supination ankle sprain: a case report of an accidental injury event in the laboratory. *American Journal of Sports Medicine* **37(4)**:822–827 DOI 10.1177/0363546508328102.

Fuchs M, Liu R, Malagoli Lanzoni I, Munivrana G, Straub G, Tamaki S, Yoshida K, Zhang H, Lames M. 2018. Table tennis match analysis: a review. *Journal of Sports Sciences* **36(23)**:2653–2662 DOI 10.1080/02640414.2018.1450073.

Iino Y, Kojima T. 2009. Kinematics of table tennis topspin forehands: effects of performance level and ball spin. *Journal of Sports Sciences* **27(12)**:1311–1321 DOI 10.1080/02640410903264458.

Kasai J, Mori T. 1998. A qualitative 3D analysis of forehand strokes in table tennis. In: Lees A, Maynard I, Hughes M, Reilly T, eds. *Science and Racket Sports II*. London: E. & F.N. Spon, 201–205.

Kibler WB, Van der Meer D. 2001. Mastering the kinetic chain, in world-class tennis technique. *Journal of Champaign Ill: Human Kinetics* **57**:99–113.

Lam W-K, Fan J-X, Zheng Y, Lee WC-C. 2018. Joint and plantar loading in table tennis topspin forehand with different footwork. *European Journal of Sport Science* **19(4)**:471–479 DOI 10.1080/17461391.2018.1534993.

Malagoli Lanzoni I, Di Michele R, Merni F. 2014. A notational analysis of shot characteristics in top-level table tennis players. *European Journal of Sport Science* **14(4)**:309–317 DOI 10.1080/17461391.2013.819382.

Malagoli Lanzoni I, Bartolomei S, Di Michele R, Fantozzi S. 2018. A kinematic comparison between long-line and cross-court top spin forehand in competitive table tennis players. *Journal of Sports Sciences* **36(23)**:2637–2643 DOI 10.1080/02640414.2018.1456394.

Myers J, Lephart S, Tsai Y, Sell T, Jolly J. 2008. The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences* **26(2)**:181–188 DOI 10.1080/02640410701373543.

Poizat G, Thouvarecq R, Seve C. 2004. A descriptive study of the rotative topspin and of striking topspin of expert table tennis players. *Science and Racket Sports* **3**:110–115.

Qian J, Zhang Y, Baker JS, Gu Y. 2016. Effects of performance level on lower limb kinematics during table tennis forehand loop. *Acta of Bioengineering and Biomechanics* **18(3)**:149–155.

Rajabi R, Johnson GM, Alizadeh MH, Meghdadi N. 2012. Radiographic knee osteoarthritis in ex-elite table tennis players. *BMC Musculoskeletal Disorders* **13(1)**:12 DOI 10.1186/1471-2474-13-12.

Reid M, Elliott B, Alderson J. 2008. Lower-limb coordination and shoulder joint mechanics in the tennis serve. *Medicine and Science in Sports and Exercise* **40(2)**:308–315 DOI 10.1249/mss.0b013e31815c6d61.

Seeley MK, Funk MD, Denning WM, Hager RL, Hopkins JT. 2011. Tennis forehand kinematics change as postimpact ball speed is altered. *Journal of Sports Biomechanics* **10(4)**:415–426 DOI 10.1080/14763141.2011.629305.

Walshe AD, Wilson GJ, Ettema GJ. 1998. Stretch-shorten cycle compared with isometric preload: contributions to enhanced muscular performance. *Journal of Applied Physiology* **84(1)**:97–106 DOI 10.1152/jappl.1998.84.1.97.

Wang M, Fu L, Gu Y, Mei Q, Fu F, Fernandez J. 2018. Comparative study of kinematics and muscle activity between elite and amateur table tennis players during topspin loop against backspin movements. *Journal of Human Kinetics* **64(1)**:25–33 DOI 10.1515/hukin-2017-0182.

Zemkova E, Muyor JM, Jelen M. 2018. Association of trunk rotational velocity with spine mobility and curvatures in para table tennis players. *International Journal of Sports Medicine* **39(14)**:1055–1062 DOI 10.1055/a-0752-4224.

Zhang Y, Awrejcewicz J, Goethel M, Levadnyi I, Gu Y. 2017. A comparison of lower limb kinematics between superior and intermediate players in table tennis forehand loop. *ISBS Proceedings Archive* **35**:40.