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Effects of shoelace tightness on lower limb biomechanics and subjective perception during lateral shuffle in basketball

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Purpose: Shoelace tightness is an important factor that may influence basketball players' performance and injury risk during shuttle slip movement. This study aimed to examine the effects of shoelace tightness on shoelace tension, lower limb kinematics and kinetics, and subjective perception in basketball players. *Methods*: Sixteen male college basketball players performed lateral shuffle movements with their dominant foot landing on a force plate under three shoelace tightness conditions (loose, comfortable and tight). A motion capture system and a force plate were used to measure lower limb kinematics and kinetics, respectively. A customized wireless shoelace tension system was used to measure shoelace tension at three locations on the dorsum of the foot. Visual analogue scales were used to assess perceived comfort, foot pressure and in-shoe displacement. *Results*: Shoelace tension increased with shoelace tightness (loose: 13.56 ± 6.21 N, comfortable: 16.14 ± 5.35 N, tight: 21.25 ± 6.19 N) and varied with shoelace position (front: 20.19 ± 5.99 N, middle: 13.71 ± 5.59 N, rear: 17.04 ± 6.95 N). Shoelace tightness also affected some of the ankle joint kinematics and kinetics as well as the subjective ratings of foot pressure and in-shoe displacement ($p < 0.05$). The loose shoelace increased the ankle inversion angle, while the comfortable shoelace decreased the knee negative power. The tight shoelace increased the perceived foot pressure and reduced the in-shoe movement ($p < 0.05$). *Conclusions*: Shoelace tightness could significantly affect lower limb biomechanics and subjective perception during lateral shuffle in basketball. Basketball footwear designers should consider the incorporation of multiple shoelaces or zonal lacing systems to allow athletes to fine-tune the tension across different areas of the foot.

Key words: *shoelace tightness, lateral shuffle, perceived comfort, injury-prevention, basketball shoes*

1. Introduction

Basketball is a popular sport that requires high levels of physical performance, such as speed, agility, strength and endurance [21]. However, basketball also involves frequent and intense movements, such as jumping, landing, cutting and sliding, which may increase the risk of lower limb injuries [2]. Lateral shuffle movement is a common defensive movement in basketball that involves lateral sliding with frequent direction changes. This movement requires high levels of speed, agility, balance, coordination and the ability to generate and absorb large forces at the ankle and knee joints [32]. However, lateral shuffle movement also exposes the lower limb to high mechanical loads and potential injury risks, such as ankle sprains [25], knee ligament tears [23] and patellofemoral pain syndrome [35]. Therefore, understanding the biomechanical factors that influence the performance and safety of lateral shuffle movement is crucial for basketball players and coaches.

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Footwear plays a vital role among the factors that may affect the lower limb biomechanics and injury risk in basketball. Previous studies have shown that different footwear characteristics, such as cushioning [24], [33], [36], shoe collar height [15], [18], [29], traction [16], [34] and torsional stiffness [5], can influence joint kinematics and kinetics of the lower extremity during basketball-specific tasks [1]. One of the footwear characteristics that has received less attention in the literature is shoelace tightness. Shoelace tightness refers to the tension applied to the shoelaces by the wearer or by an automatic lacing system. Results showed that shoelace tightness can affect the fit and comfort of the shoe as well as the interaction between the foot and the shoe during dynamic activities [8], [11]. Shoelace tightness may also have implications for the lower limb biomechanics and injury risk in basketball, as it may alter the loading and stability of the ankle and knee joints.

Shoelace tightness is an essential factor that may influence basketball players' performance and injury risk. However, there is limited evidence on how shoelace tightness affects the lower limb biomechanics and perceived comfort during lateral shuffle movement in basketball games. Most existing studies have focused on running or walking tasks and have used subjective methods to control or measure shoelace tightness [8]–[11]. Moreover, there is a lack of consensus on whether tighter or looser shoelaces are more beneficial for performance and injury prevention. Some studies have suggested that tighter shoelaces can enhance foot stability and reduce foot slippage within the shoe, possibly reducing the risk of ankle sprains and blisters [8]. Other studies have indicated that looser shoelaces can allow more natural foot motion and reduce dorsal foot pressure, improving comfort and reducing the risk of overuse injuries [10]. In addition, previous studies have only relied on subjective methods to evaluate the changes in shoelace tightness during basketball activities [7]–[11]. To the author's knowledge, few studies have quantified the shoelace tension at different locations on foot during basketball movements due to the lack of reliable shoelace tension measurement equipment. In this study, we measured the peak shoelace tension at the front, middle and rear positions on the dorsum of the foot to investigate the optimal distribution of shoelace tension for lateral shuffle movement.

Therefore, this study aimed to investigate the shoelace tension distribution at different foot positions, the effects of shoelace tightness on lower limb biomechanics, and perceived comfort during lateral shuffles in basketball. We hypothesized that a) shoelace tension varied with different positions (front, middle, rear), b) shoelace tightness significantly affects the joint angles, moments, powers and work of the ankle and knee joints during lateral shuffles, and c) shoelace tightness has significant effect on the subjective ratings of perceived foot dorsum pressure, in-shoe displacement and comfort.

2. Materials and methods

2.1. Participants

The sample size for this study was calculated using G*Power software (version 3.1.9.2) [14], based on a one-way repeated measures ANOVA. An alpha level of 0.05, a power of 0.80 and a medium effect size of 0.35 acquired by a pilot study were used as the parameters. A minimum sample size of 15 participants was required to detect a significant difference among the three measurements. To account for potential dropouts, 16 male college basketball players were recruited. The average age, height, body mass and body mass index (BMI) of the participants were 20.7 ± 1.8 years, 178.6 ± 5.5 cm, 70.0 ± 6.5 kg and 21.9 ± 1.6 kg/m^2, respectively. The participants were selected according to the following inclusion criteria: a) age between 18 and 23 years, b) at least 4 years of basketball experience, c) at least 8 hours of weekly training, d) right leg dominance, e) shoe size between 42 and 44 (European size). The following exclusion criteria were applied: a) lower limb injuries in the past six months; b) foot deformities; c) sensory impairments in the foot; d) refusal to sign the informed consent form. The aims and procedures of the study were explained to the participants before the experiment and their written consent was obtained. This study was approved by the ethics committee of the Shanghai University of Sport (No. 102772022RT094).

2.2. Instrumentation and materials

In this study, kinematic data were collected using a 10-camera motion capture system (Nexus, Vicon Motion Systems, Ltd., Oxford, UK) with a sampling frequency of 200 Hz. A Kistler force plate (model 9287C, Kistler, Winterthur, Switzerland) and a customized wireless shoelace tension system were used to collect ground reaction forces and shoelace tension force simultaneously with a sampling frequency of 1000 Hz. To achieve synchronization, the wireless shoelace tension system, which possesses a data channel for capturing external signals, was connected to the Vicon motion capture system via a BNC cable. The wireless system commenced data collection first. When the Vicon system began its data collection, it sent a square wave signal to the wireless system. Both systems utilized the initiation moment of this square wave signal to align their data collection processes, ensuring synchronized datasets. A total of 36 reflective markers were applied according to the marker set of the lower limb Plug-in-Gait (PiG) model [4] (Fig. 1). Passive, reflective markers were placed bilaterally on the ankle (lateral/medial malleolus), knee (lateral/medial epicondyle) and hip (greater trochanter). Additionally, we placed stiff marker triads on each thigh (four markers) and shank (three markers), four markers on the pelvis (left/right anterior superior iliac spine, left/right posterior superior iliac spine) and four markers on each foot (calcaneus, first/fifth metatarsal, hallux) [38].

Fig. 1. Marker placement for each subject from the anterior view

A customized wireless shoelace tension system with three micro force transducers (Fig. 2) was used to collect the shoelace tension during the shuffle steps. The micro force transducers were custom-made miniature sensors with a diameter of 12.98 mm, a mass of 10.16 g, an accuracy of 0.01 N and a range of 0–50 N. The sensors had good linearity and repeatability [37]. The output voltage signal of the sensors was linearly correlated with the load ($P < 0.0001$, $R^2 = 0.9999$) and the coefficient of variation of the measurement values of three sensors under different loads was less than 0.004. The data acquisition system for the sensors had a sampling frequency of 1000 Hz.

Fig. 2. Three micro force transducers placed in this study

To control for the effect of different basketball shoes on the results, this study used conventional high-top basketball shoes (361 Co., Ltd. Xia men, China) with six pairs of eyelets. The original shoe laces were replaced with steel-core shoe laces as test shoe laces to minimize the measurement error caused by the material elongation of shoe laces during testing. The X-lacing method was applied, and three shoelace tension sensors were positioned between the first and second, third and fourth, and fifth and sixth eyelets (Fig. 3), corresponding to the anterior, middle and posterior parts of the dorsum of the foot, respectively.

2.3. Procedure

Before the test, the participants wore designated sportswear and performed a 5–10 min warm-up to prevent injuries. To control the experimental variables, each participant wore the same socks. The participants received instructions on the test procedure, put on the test instruments and practised the test movement under the guidance of an experimenter until they mastered it. During the test, the experimenter monitored the participants' safety. The shoelace tension conditions were loose, comfortable and tight. The comfortable condition was the participants' habitual shoelace tightness; the loose condition was when the static tension value was zero [11]; the tight condition was when the shoelace was tightened to the point of causing pain but not impairing the movement.

A buckle-type automatic lacing system was used on the shoe laces to maintain their tightness and prevent them from changing or loosening due to lacing. The buckle was fixed on the lateral malleolus of the foot and the free end of the shoelace was fixed by a buckle of automatic lacing system, which could adjust shoelace tightness by mechanical structure. The static recording was carried out after markers were placed and participants were in anatomical positions. The participants were asked to stand two meters from the force plate and perform a lateral shuffle movement by stepping on the force plate with their dominant foot and sliding in the opposite direction as fast as possible. The dominant foot was identified by asking subjects which foot they would use to kick a ball [6]. At least three successful trials were performed for each shoelace tension condition. The order of shoelace tension conditions was randomized for each participant to avoid any order effects [17].

After the test, the participants rated their subjective perception of foot dorsum pressure, perceived in-shoe displacement and perceived comfort using three separate 150 mm visual analogue scales (VAS) [22], [27]. Higher foot dorsum pressure ratings indicated greater foot restraint, higher perceived in-shoe displacement ratings indicated more relative movement and less stability between foot and shoe, and higher perceived comfort ratings indicated better comfort perception [22].

2.4. Data processing

Visual 3D 6.0 (C-Motion, Rockville, MD, United States) was used to process kinematic and kinetic data. Kinematic data and ground reaction force (GRF) were filtered with a fourth-order, low-pass Butterworth filter with a cutoff frequency of 12 and 50 Hz separately [12]. Foot contact and foot off were defined using a GRF threshold of 10 N. Stance phase time was defined as the time elapsed between foot contact and the consecutive foot off the same leg. The GRF values were normalized by the body weight and were time-normalized against 101 data points corresponding to the stance phase of the lateral shuffle [3]. The kinematic variables in this study were joint angle, range of motion and peak angular velocity of the knee, and ankle joints in sagittal, coronal, and transverse planes. The kinetic variables were peak joint moment, stiffness, maximum positive/negative joint power, and joint work of knee and ankle joints in sagittal, coronal and transverse planes.

2.5. Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) was used to investigate the effects of shoelace tightness and position on peak shoelace tension during lateral shuffle movement. A one-way ANOVA with repeated measures was used to investigate the effects of shoelace tightness on lower limb kinematics and kinetics, and subjective during lateral shuffle movement. When significant effects were found, Tukey's post hoc test was used for pairwise comparisons [20]. The significance level was set at 0.05. The statistical analysis was performed using SPSS 21.0 (IBM Corp., Armonk, NY). Data were presented as mean ± standard deviation (Mean ± SD).

3. Results

3.1. Shoelace tension

The shoelace tension at different positions (front, middle, rear) under different shoelace tightness conditions (loose, comfortable, and tight) is collected in Table 1. Results showed that shoelace tightness ($F(1.85, 14.82) = 23.61$, $p < 0.0001$) and position ($F(1.33, 10.67) = 6.66$, $p = 0.02$) had a significant

Table 1 Shoelace tension at different positions (front, middle, rear) under three tightness conditions (loose, comfortable, tight) during lateral shuffle (Unit: N)

Tightness	Front	Middle	Rear	*P* value		
				Position	Tightness	Interaction
Loose	17.26 ± 6.19	11 ± 5.19	12.41 ± 5.98	0.020*	<0.0001*	0.096
Comfortable	18.49 ± 4.46	12.94 ± 5.14	16.99 ± 5.30			
Tight	24.81 ± 4.64	17.21 ± 5.03	21.72 ± 6.69			

The statistical markers (*) indicate these differences were statistically significant.

effect on shoelace tension and there was no significant interaction between them ($F(2.71, 21.69) = 2.45$, $p = 0.096$). The peak tension of the shoelace increased with the lacing tightness (loose: 13.56 ± 6.21 N, comfort: 16.14 ± 5.35 N, Tight 21.25 ± 6.19 N). The peak tension of the middle (13.71 ± 5.59 N) part of the shoelace was significantly lower than that of the front (20.19 ± 5.99 N, $p < 0.0001$) and rear (17.04 ± 6.95 N, $p = 0.006$) part of the shoelace.

3.2. Knee and ankle kinematics

The knee and ankle joint kinematics during lateral shuffle for different lace-tightness states are shown in Table 2. For the knee joint, there were no significant differences observed in peak extension angle ($p = 0.646$), peak flexion angle ($p = 0.344$), flexion/extension range of motion ($p = 0.406$), peak inversion angle ($p = 0.147$), peak eversion angle ($p = 0.328$), inversion/eversion range of motion ($p = 0.247$) or peak inversion velocity ($p = 0.511$) among the loose, comfortable and tight lace-tightness states.

Regarding the ankle joint, no significant differences were found in peak dorsiflexion angle ($p = 0.268$), peak plantarflexion angle ($p = 0.119$), dorsiflexion/plantarflexion range of motion ($p = 0.292$), or peak eversion angle ($p = 0.089$) among the three lace-tightness states. However, significant differences were observed in peak inversion angle ($p < 0.0001$), inversion/eversion range of motion ($p = 0.006$), and peak inversion velocity ($p = 0.006$). Post-hoc analysis revealed that the loose condition exhibited significantly greater peak inversion angle and inversion/eversion range of motion compared to the comfortable and tight conditions ($p < 0.05$), while the comfortable condition demonstrated significantly lower peak inversion velocity compared to the loose ($p = 0.006$) and tight conditions ($p = 0.007$).

3.3. Knee and ankle kinetics

The results of the statistical analysis of the knee and ankle joint kinetics during lateral shuffle for different lace-tightness states are shown in Table 3. The results showed that there were no significant differences in the peak extension moment, peak flexion moment, peak inversion moment, peak eversion moment, and peak positive power of the knee joint among the three shoelace tightness conditions ($p > 0.05$). However, there were significant differences in the peak negative power ($p = 0.007$) and net joint work ($p = 0.015$) of the knee joint among the conditions. The knee joint had a lower peak negative power and net joint work in the comfortable condition than in the loose ($p = 0.011$) and tight conditions ($p = 0.036$). However, the knee joint had a higher net joint work in the comfortable condition than in the loose ($p = 0.049$) and tight conditions ($p = 0.024$).

The results also showed that there was a significant difference in the peak dorsiflexion moment of the ankle joint among the three shoelace tightness conditions ($p < 0.05$). The ankle joint had a higher peak dorsiflexion moment in the tight condition than in the comfortable ($p = 0.024$) and loose condition

Table 2. Knee and ankle joint kinematics during lateral shuffle for different lace-tightness states

Joint	Variable	Loose	Comfortable	Tight	*P*-value
Knee	Peak extension angle [°]	–7.1 ± 11.3	–7.2 ± 5.4	–8.7 ± 7.2	0.646
	Peak flexion angle [°]	–63.8 ± 10.2	–66.1 ± 7.1	–65.7 ± 7.5	0.344
	Flexion/Extension range of motion [°]	56.7 ± 9.0	59.0 ± 7.2	56.9 ± 8.6	0.406
	Peak inversion angle [°]	2.0 ± 8.0	–1.5 ± 9.2	–2.9 ± 4.4	0.147
	Peak eversion angle [°]	–11.4 ± 5.4	–11.9 ± 7.3	–12.9 ± 7.3	0.328
	Inversion/eversion range of motion [°]	10.3 ± 7.7	9.8 ± 6.2	9.9 ± 5.2	0.247
	Peak inversion velocity [°/s]	156.9 ± 57.6	158.5 ± 57.2	143.1 ± 48.4	0.511
Ankle	Peak dorsiflexion angle [°]	35.9 ± 9.9	34.8 ± 8.2	33.5 ± 9.3	0.268
	Peak plantarflexion angle [°]	–28.4 ± 9.7	–31.1 ± 7.2	–29.4 ± 8.9	0.119
	Dorsiflexion/plantarflexion range of motion [°]	64.3 ± 10.8	66 ± 8.4	62.9 ± 10.3	0.292
	Peak inversion angle [°]	**51.3 ± 7.3**	**49.5 ± 6.9***	**47.9 ± 8.3*#**	**<0.0001**
	Peak eversion angle [°]	11.1 ± 5.7	13.3 ± 5.2	11.5 ± 5.5	0.089
	Inversion/eversion range of motion [°]	**40.2 ± 10.4**	**36.2 ± 9.2***	**36.4 ± 10.7***	**0.006**
	Peak inversion velocity [°/s]	**991.8 ± 219.7**	**818.8 ± 176.5***	**914.9 ± 248.9#**	**0.006**

* indicates a significant difference between the loose condition ($P < 0.05$), # indicates a significant difference between the comfortable condition ($P < 0.05$).

Table 3. Knee and ankle joint kinetics during lateral shuffle for different lace-tightness states

Joint	Plane	Variable	Loose	Comfortable	Tight	*P*-value
Knee	Sagittal plane	Peak extension moment [N·m/kg]	2.38 ± 0.47	2.33 ± 0.56	2.50 ± 0.53	0.113
		Peak flexion moment [N·m/kg]	–0.79 ± 0.25	–0.73 ± 0.27	–0.74 ± 0.26	0.558
		Peak positive power [W/kg]	9.01 ± 2.55	9.87 ± 3.99	9.27 ± 2.46	0.600
		Peak negative power [W/kg]	**–12.71 ± 3.71**	**–10.21 ± 4.87***	**–12.92 ± 4.89#**	**0.007**
		Net joint work [J/kg]	**–0.01 ± 0.20**	**0.18 ± 0.34***	**0.04 ± 0.28#**	**0.015**
	Coronal plane	Peak inversion moment [N·m/kg]	1.97 ± 0.63	1.80 ± 0.55	1.84 ± 0.64	0.449
		Peak eversion moment [N·m/kg]	–0.15 ± 0.07	–0.15 ± 0.11	–0.15 ± 0.15	0.987
		Peak positive power [W/kg]	1.45 ± 0.91	1.66 ± 0.94	1.56 ± 0.79	0.654
		Peak negative power [W/kg]	–1.49 ± 0.76	–1.46 ± 0.77	–1.46 ± 0.67	0.924
		Net joint work [J/kg]	–0.03 ± 0.05	–0.01 ± 0.06	0.00 ± 0.06	0.127
Ankle	Sagittal plane	**Peak dorsiflexion moment [N·m/kg]**	**0.03 ± 0.03**	**0.03 ± 0.03**	**0.06 ± 0.04*#**	**0.020**
		Peak plantarflexion moment [N·m/kg]	–2.50 ± 0.43	–2.48 ± 0.57	–2.51 ± 0.50	0.916
		Peak positive power [W/kg]	10.98 ± 3.39	10.07 ± 3.91	10.29 ± 4.39	0.623
		Peak negative power [W/kg]	–18.75 ± 6.55	–16.89 ± 8.70	–17.29 ± 5.89	0.615
		Net joint work [J/kg]	0.14 ± 0.24	0.20 ± 0.23	0.13 ± 0.23	0.221
	Coronal plane	Peak inversion moment [N·m/kg]	0.12 ± 0.11	0.16 ± 0.14	0.12 ± 0.07	0.289
		Peak eversion moment [N·m/kg]	–0.98 ± 0.50	–0.96 ± 0.50	–1.07 ± 0.57	0.474
		Peak positive power [W/kg]	1.67 ± 0.77	1.72 ± 1.00	1.66 ± 0.99	0.897
		Peak negative power [W/kg]	–4.38 ± 3.84	–3.38 ± 1.94	–4.20 ± 2.69	0.344
		Net joint work [J/kg]	–0.13 ± 0.13	–0.13 ± 0.12	–0.11 ± 0.10	0.521

* indicates a significant difference between the loose condition ($P < 0.05$), # indicates a significant difference between the comfortable condition ($P < 0.05$).

($p = 0.011$). There were no significant differences in the other kinetic variables of the ankle joint among the conditions ($p > 0.05$).

3.4. Subjective perception

Results depicted in Fig. 4 showed that there was a significant difference in foot dorsum pressure among the three shoelace tightness conditions ($p < 0.05$). The foot dorsum pressure was higher in the tight conditions than in the loose and comfortable conditions. There was also a significant difference in in-shoe displacement among the conditions ($p < 0.05$). The in-shoe displacement was lower in the tight condition than in the loose and comfortable condition. However, there was no significant difference in perceived comfort among the conditions ($p > 0.05$).

4. Discussion

This study aimed to investigate the effects of shoelace tightness on lower limb biomechanics and perceived comfort during lateral shuffle movement in basketball. The results showed that shoelace tightness had a significant effect on some of the knee joint kinematics and kinetics as well as the subjective ratings of foot dorsum pressure and perceived in-shoe displace-

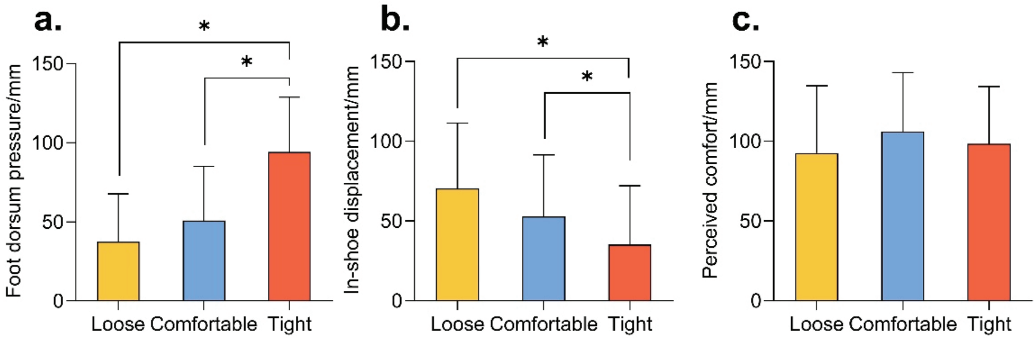

Fig. 3. Effects of shoelace tightness on perceived a) foot dorsum pressure, b) in-shoe displacement, c) comfort during shuffle slip movement

ment. However, shoelace tightness did not affect most of the ankle joint kinematics and kinetics or the perceived comfort.

4.1. Effect of shoelace position and tightness on shoelace tension

The results of this study showed that shoelace tightness and position had significant effects on shoelace tension during lateral shuffle movement in basketball. The peak tension of the shoelace increased with the lacing tightness. The peak tension of the middle part of the shoelace was significantly lower than that of the front and rear part of the shoelace, which may be caused by the different curvature and deformation of the foot at different positions. The front part of the foot may experience more bending and stretching during lateral shuffle movement, resulting in higher shoelace tension. The rear part of the foot may be more restrained by the shoe collar and heel counter, leading to higher shoelace tension. The middle part of the foot may have less movement and deformation, resulting in lower shoelace tension. This finding suggests that the distribution of shoelace tension may vary with different foot positions and movements, which should be considered in the design and optimization of basketball shoes and lacing systems.

4.2. Effect of shoelace tightness on knee and ankle joint kinematics

This study showed that shoelace tightness had significant effects on some of the ankle joint kinematics, but not on the knee joint kinematics, during lateral shuffle movement in basketball. The ankle joint had a higher peak inversion angle in the loose condition than in the comfortable and tight conditions, which may indicate that the loose shoelace condition allowed for more freedom and natural motion of the foot within the shoe, increasing the inversion of the ankle joint. This may have implications for the injury risk of the ankle joint, as excessive inversion of the ankle joint has been associated with ankle injuries [13]. However, the knee joint kinematics were not affected by the shoelace tightness, which may be due to the inherent stability and biomechanical structure of the knee joint [19], which may be less susceptible to variations in external factors such as shoelace tightness. The knee's complex system of ligaments and muscles could provide a consistent kinematic pattern that is not easily altered by changes in footwear tightness. Additionally, the strong structural design and envelopment provided by basketball shoes themselves may further diminish the influence of shoelace tightness on knee joint kinematics. This suggests that while shoelace tightness can influence ankle movement and potential injury risk, it does not have the same effect on the knee joint during lateral shuffle movements in basketball.

4.3. Effect of shoelace tightness on knee and ankle joint kinetics

The results of this study showed that shoelace tightness had significant effects on some of the knee and ankle joint kinetics during lateral shuffle movement in basketball. The knee joint had a lower peak negative power and net joint work in the comfortable condition than in the loose and tight conditions, which may indicate that the comfortable shoelace condition reduced the energy absorption and dissipation of the knee joint during lateral shuffle movement [31]. This may have implications for the performance and fatigue of the knee joint, as lower energy absorption and dissipation may reduce the metabolic cost and muscle activation of the knee joint [28]. However, the peak positive power of the knee joint was not affected by the shoelace tightness, suggesting that the shoelace tightness may not have a large impact on the energy generation and propulsion of the knee joint during lateral shuffle movement. The ankle joint had a higher peak dorsiflexion moment in the tight condition than in the loose condition, which may indicate that the tight shoelace condition increased the resistance and stiffness of the shoe upper, enhancing the plantarflexion force and torque of the ankle joint during lateral shuffle movement. This may have implications for the performance and injury risk of the ankle joint, as higher plantarflexion force and torque may increase the speed and agility of the ankle joint, but also increase the stress and strain on the Achilles tendon and the plantar fascia [30]. However, the other kinetic variables of the ankle joint were not affected by the shoelace tightness, suggesting that the shoelace tightness may not have a large impact on the energy absorption, generation and dissipation of the ankle joint during lateral shuffle movement.

4.4. Effect of shoelace tightness on subjective perception

The results of this study showed that shoelace tightness had significant effects on the subjective ratings of foot dorsum pressure and perceived in-shoe displacement, but not on the perceived comfort, during lateral shuffle movement in basketball. The foot dorsum pressure was higher in the tight condition than in the loose and comfortable conditions, which may indicate that the tight shoelace condition increased the compression and friction of the shoe upper on the foot, causing discomfort and pain on the foot dorsum. The in-shoe displacement was lower in the tight condition than in the loose and comfortable conditions, which may indicate that the tight shoelace condition reduced the relative movement and slippage of the foot within the shoe, improving the fit and stability of the shoe. However, the perceived comfort was not affected by the shoelace tightness, which may indicate that the shoelace tightness did not have a clear or consistent influence on the overall comfort perception of the shoe. This may be due to the trade-off between the foot dorsum pressure and the in-shoe displacement, as well as the individual preferences and expectations of the participants. Previous studies have shown that comfort perception is a complex and subjective phenomenon that depends on various factors, such as biomechanical, physiological, psychological and environmental factors [22], [26]. Therefore, the shoelace tightness may not be the main or sole determinant of the comfort perception of the shoe.

4.5. Limitations

This study has some limitations that should be acknowledged. First, we only included male college basketball players, which may limit the generalizability of the results to other populations, such as female, younger, older or recreational basketball players. Second, this study only measured the shoelace tension at three locations on the dorsum of the foot. Different locations of shoelace tension may have different effects on lower limb biomechanics and perceived comfort during lateral shuffle movement. Future studies should measure the shoelace tension at more locations on the foot and investigate the optimal distribution of shoelace tension for lateral shuffle movement. Last but not least, the study only used one type of conventional high-top basketball shoes with six pairs of eyelets and the X-lacing method, which may not represent the diversity and variability of the basketball shoes and lacing methods available in the market. Future studies should compare the effects of different types of basketball shoes and lacing methods on the lower limb biomechanics and perceived comfort during lateral shuffle movement.

5. Conclusions

This study investigated the effects of shoelace tightness on lower limb biomechanics and perceived comfort during lateral shuffle movement in basketball. The results showed that shoelace tightness and position had significant effects on shoelace tension, and that shoelace tightness had significant effects on some of the ankle joint kinematics and kinetics as well as the subjective ratings of foot dorsum pressure and perceived in-shoe displacement. However, shoelace tightness did not affect the knee joint kinematics and kinetics or the perceived comfort. The findings suggest that neither too tight nor too loose shoelaces may be optimal for performance, stability, and injury prevention during lateral shuffle movement. Therefore, it is recommended that basketball footwear designer consider the incorporation of multiple shoelaces or zonal lacing systems to allow athletes to fine-tune the tension across different areas of the foot. Future studies should consider using more ecological and realistic tasks and environments, comparing different types of basketball shoes and lacing methods, and including different populations of basketball players.

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