©Journal of Sports Science and Medicine (2020) **19**, 620-626
http://www.jssm.org

Research article

Comfort and Ground Reaction Forces in Flat-Footed Female Runners: Comparison of Low-Dye Taping versus Sham Taping

Hui Li Alvina Koh [1], Wei-Hsiu Lin [2] and Pui Wah Kong [1]✉
[1] Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, Singapore; [2] Department of Physical Education, Health and Recreation, National Chiayi University, Chiayi, Taiwan

Abstract

The purpose of this study was to examine the effects of low-Dye tape on comfort and ground reaction forces (GRF) in flat-footed female runners. A randomized cross-over study was conducted on 15 flat-footed female recreational runners. Participants ran at three speeds (9, 10, 11 km/h) under two conditions: low-Dye and sham taping. Comfort level was assessed using a 150-mm visual analog scale. GRF data were collected using an instrumented treadmill. Stance time, peak forces, and loading rates were extracted. Low-Dye taping showed a lower comfort level (low-Dye, 63.8 (24.3) mm, sham 122.0 (16.0) mm, mean difference [95% confident intervals], -58.2 [68.2, 48.2] mm, $p < 0.001$). For all biomechanical variables, there was no interaction (taping condition × speed) effect or difference between taping conditions. As running speed increased, there was a decrease in stance time ($p < 0.001$) and increase in loading rate ($p = 0.009$), impact peak ($p = 0.004$), active peak ($p < .001$), breaking peak ($p < 0.001$), propulsive peak ($p < 0.001$), medial peak ($p < 0.001$), and lateral peak ($p < 0.001$). Compared with sham taping, application of low-Dye taping was less comfortable but did not alter running ground reaction forces among flat-footed female runners.

Key words: Peak force, loading rate, visual analogue scale, low-arch, non-elastic sports tape.

Introduction

Running is greatly known for its positive impact on general health and longevity, but it may also put individuals at risk of injuries. The incidence of running-related injuries per 1000 h of running ranged from 2.5 in long-distance track and field athletes to 33.0 among novice runners (Videbaek et al., 2015). Anatomical malalignment of the foot is one of the many factors associated with running-related injuries, and flat-footed runners are reported more likely to sustain soft-tissue and overuse injuries (Gijon-Nogueron and Fernandez-Villarejo, 2015). Low-arch or flat-foot is characterized by forefoot abduction, hindfoot valgus and a decrease in medial arch height (Huang et al., 1993). Flat-footed runners are susceptible to increased stress and pain experienced on the medial aspects of the lower extremity (Bandholm et al., 2008). In an attempt to reduce the risk of sustaining lower extremity injuries in runners with flat-feet, non-surgical interventions such as anti-pronation taping has been put in place to reduce foot pronation (Cheung et al., 2011).

The effects of anti-pronation taping are evident in the increase in navicular height and re-distribution of plantar pressure patterns in the medial and lateral midfoot regions (Newell et al., 2015; Nolan and Kennedy, 2009). While low-Dye taping is generally effective in reducing pronation of the foot in the literature, most studies either focused only on male participants or combined results of both sexes without reporting the outcomes from male and female participants separately (Franettovich et al., 2008; Newell et al., 2015). In a study on external ankle taping, no biomechanical differences during sprinting were found between low-Dye and sham taping in a group of young males (Moore et al., 2020). There are, however, biomechanical differences in locomotion between males and females (Chiu and Wang, 2007; Ferber et al., 2003; Hennig, 2001; Stefanyshyn et al., 2003). For example, females were found to have greater ankle motion, vertical ground reaction forces (GRF), and higher tibialis anterior muscle activation during walking compared to males (Chiu and Wang, 2007). Female runners also exhibited higher loading rate of the vertical GRF and reduced peak plantar pressure than their male counterparts (Hennig, 2001; Stefanyshyn et al., 2003). Given these known differences between sexes, the effect of taping on running biomechanics observed in males or in cases where males and females were treated as one group may not be applicable to female runners.

In the literature, there were only two studies investigating the effect of taping in females (Ator et al., 1991; Vicenzino et al., 1997). In both studies, the reported outcome was limited to a static measure of vertical navicular height which was found increased immediately after the application of tape (Ator et al., 1991; Vicenzino et al., 1997). Other dynamic variables such as GRF may offer greater insights on the loading characteristics during running to better indicate the risks of injuries. Recent study suggests that peak breaking force is associated with a significantly higher injury hazard ratio in female recreational runners (Napier et al., 2018). Furthermore, assessment of comfort level may also be useful to provide a more holistic evaluation of the taping intervention as shoe inserts that are comfortable have been shown to decrease injury frequency (Mündermann et al., 2001). In footwear research, lower perceived comfort is associated with reduction in the variability of running kinematics or a more repetitive running pattern (Mohr et al., 2017). This finding is line with the new paradigms of 'preferred movement path' and 'comfort filter' for injury prevention, suggesting that a runner intuitively selects a comfortable product that allows them to run in their preferred movement path (Nigg et al., 2015). In general, application of tapes in the foot and ankle region is

Received: 04 March 2020 / Accepted: 29 July 2020 / Published (online): 13 August 2020

often perceived as uncomfortable (Hyland et al., 2006). To better understand the effects of low-Dye taping on females, a comprehensive study on running biomechanics and comfort level is warranted.

The aim of this study was to examine the effects of low-Dye tape on GRF and comfort level in flat-footed female recreational runners. It was hypothesized that application of the low-Dye tape would be perceived as less comfortable and would decrease biomechanical loading when compared with sham taping.

Methods

Study design

This controlled laboratory study adopted as a within-subject, single-blind, randomized crossover design in which participants served as their own control. Low-Dye taping was used to reduce pronation of the foot and sham taping acted as a placebo (Newell et al., 2015). To blind participants from the experiment / placebo condition, they were informed that two different types of taping techniques would be compared. Participants were required to run at three different speeds on a treadmill under each taping condition where GRF data were collected.

Participants

This study was approved by the Nanyang Technological University Institutional Review Board (Protocol Number: IRB-2017-08-011). An *a-priori* power analysis for difference between two conditions (low-Dye versus sham, matched pairs) showed that at least 15 participants (α = 0.05, effect size = 0.80 large, power = 0.80) were required (Ng et al., 2020). In the present study, 15 female volunteers provided written informed consent to participate (Table 1). After filling in a background survey, they were screened for foot type using the following three methods:

(i) Arch index (AI). Participants walked over the EMED® M platform (Novel GmbH, Germany) using a 2-step approach. Dynamic arch index (AI) obtained through the Novel software to indicate foot posture (Murley et al., 2009). An AI of more than or equals to 0.26 was considered flat foot, reflecting a large midfoot area compared with the total foot area (Cavanagh and Rodgers, 1987). This method of classifying flat foot has been wide used in other studies (Ng et al., 2020; Tong and Kong, 2016).

(ii) Navicular drop test. Navicular drop was measured as the change in height of the navicular tuberosity when the foot was moved from subtalar joint neutral position (non-weight bearing) to a resting calcaneal stance position (weight bearing). A navicular drop value of more than or equals to 10 mm was considered flat foot, reflecting substantial lowering of the foot arch under weight bearing condition. This technique is one of the most commonly used clinical measurement and has high intra-tester reliability and concurrent validity (Christensen et al., 2014).

(iii) Resting calcaneal stance position (RCSP). Participants were asked to stand in a relaxed manner with equal weight on both legs and a protractor was used to measure the angle between the calcaneus bisection line and the vertical line drawn on the leg. A RCSP of more than or equals to 4° valgus was considered flat foot, as the standing foot posture is everted from the neutral position. This test has been shown as a reliable and acceptable technique (Sell et al., 1994).

Table 1. Demographic and anthropometric characteristics of participants.

Characteristics		Mean (SD)
Age (years)		22.5 (2.2)
Body Mass (kg)		52.3 (5.8)
Height (m)		1.60 (0.05)
Foot Size (UK)		5.7 (1.0)
No. of running session (per week)		2.4 (0.6)
Running mileage per session[a]	Less than 2 km	0
	2 km to 3 km	11
	3 km to 4 km	2
	4 km to 5 km	2
Arch index	Right	0.27 (0.03)
	Left	0.28 (0.03)
Navicular Drop (mm)	Right	12.9 (3.3)
	Left	13.5 (2.9)
Resting calcaneal stance position (°)	Right	13.4 (2.9)
	Left	12.3 (2.5)

[a] Data reported are number of participants.

If a foot fulfilled at least two out of the three criteria (AI ≥ 0.26, navicular drop ≥ 10 mm, RCSP ≥ 4 ° valgus) described above, it was considered flat. Only participants with both feet classified as flat-foot were recruited. The overall inclusion criteria were: (a) female, (b) aged between 18 and 35 years, (c) have shoe size within UK 5 and 7 (in order to fit the standardized footwear provided), (d) were recreational runners who had been running for the past 2 months, at least twice a week for more than 2 km per session, (e) bilaterally flat-footed. Participants were excluded if they (a) have previously gone through surgeries to the legs, (b) had serious injuries to their back or legs which required more than 7 days of rest in the past 6 months prior to participation in the study, or (c) had any discomfort or pain in their back or legs at the time the study was conducted.

Experimental Procedures

Taping Conditions. Eligible participants underwent two different taping conditions with rigid 4-cm wide sports tapes (Strappal Rigid Tape, Vibraye, France), in a randomly assigned order. The two conditions are low-Dye taping and sham taping as a placebo treatment (Figure 1). For good consistency, application of the tape was done by the same researcher throughout this study. As for the low-Dye tape, two anchor strips were applied from the first metatarsophalangeal joint to the fifth metatarsophalangeal joint. In between the placement of the two anchor strips, about five to six stirrups (dependent on the participant's foot size) were then applied starting from the lateral side of the anchor strip to the medial side of the anchor strip (Vicenzino et al., 1997). In order to oppose pronation of the foot, some force was applied medially. The sham taping method was adopted from a previous study (Kelly et al., 2010) in which two anchor strips were applied from the navicular tuberosity to the fifth metatarsal styloid process, posterior to the calcaneus. In between the anchor strips were about three to four stirrups (dependent on the participant's foot size) which extended from the medial to lateral malleoli. To ensure the tape had no effect, much caution was taken such that no force was applied in the sham condition (Kelly et al., 2010). The tapes only fell off in one participant during the warm-up period. No adjustments of the tapes were needed during the actual running tests.

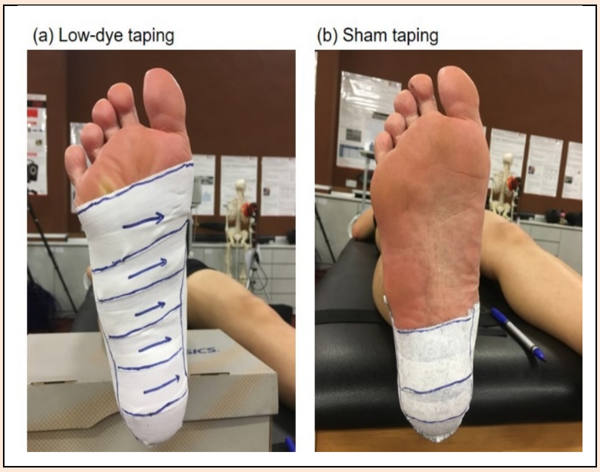

Figure 1. (A) Low-Dye taping technique. Medial force was applied in the direction of the arrows drawn on the tape. (B) Sham taping technique. No force was applied upon application of the tape.

Upon the application of the tape, participants were allowed to walk or jog slowly around the laboratory to evaluate the comfortability of the tape. Participants were given as much time as they required. Comfort level in each taping condition was assessed using a 150-mm visual analogue scale (VAS), where the 0-mm end was "Extremely Uncomfortable" and the 150-mm end was "Extremely Comfortable" (Cheung and Ng, 2007). The participants were asked to mark their perceived level of comfort anywhere throughout the continuum by drawing a vertical line perpendicular to it, and the line was measured to the nearest millimeter. Assessing comfort using VAS has been demonstrated as a reliable method in studies on footwear and inserts (Mills et al., 2010).

Running Test. Participants were given sufficient time to warm-up and stretch. After which, they were asked to run on a split-belt force-plate instrumented treadmill sampled at 1000 Hz (Bertec, Inc., Columbus, OH) at three different speeds of 9, 10, and 11km/hr. This speed range was chosen to reflect the typical jogging speeds of recreational female runners and the speeds were comparable to those used in previous studies on females (Cheung and Ng, 2007; Ferber et al., 2011; Milgrom et al., 2003). The order of speeds was randomized. To eliminate the influence of socks and footwear, all participants were given a standardized pair of socks (Erke, Performance sock, China) and neutral shoes (Asics, Patriot 8, T669N-9001, Japan) for the running test. Each running trial lasted for three minutes, with a three-minute break in between. To allow sufficient time for the participant to reach a stable running state at each speed, GRF were recorded from 2:15 for 30 seconds in each bout of running (Kluitenberg et al., 2012).

Data Processing

Raw GRF data were processed using a fourth-order Butterworth digital low-pass filter using a cut-off frequency of 110 Hz determined from residual analysis. For each running trial, 60 foot steps were extracted for analysis using a customized MATLAB R2017b script (The MathWorks, Inc., Natick, MA). Only rearfoot strikes, determined based on the existence of both impact and active peaks, were included. Non-rearfoot strikes were excluded because of the absence of impact peak force and hence impact loading rate cannot be computed. In some participants, all 60 steps were rearfoot strikes. Most participants were consistent rearfoot strikers, with very few steps (less than 5) removed due to non-rearfoot striking patterns. First, the instances of touch-down and toe-off were identified from the vertical GRF data using a threshold of 20 N. Stance time was calculated as the duration from touchdown to toe-off.

Force data were then normalized to individual participants' body weight (BW). Peak impact and active forces were identified from the vertical GRF. Loading rate was calculated from the duration of 20% to 80% between touchdown and the impact peak (Clansey et al., 2012). Next, the peak breaking, propulsive, medial, and lateral forces were determined from the anteroposterior and mediolateral GRF. To plot the mean ensemble curves, GRF data were also time-normalized to the stance phase (0 to 100%).

Statistical analysis

Statistical analyses were performed on IBM™SPSS™ Statistics (Version 24.0, SPSS Inc., Chicago, IL, USA). The means, standard deviations, and 95% confidence intervals (CI) were calculated. For comfort level, normality of the VAS data was verified using the Shapiro-Wilk test. A paired t-test was performed to compare the VAS scores between the sham and low-Dye taping conditions. Statistical significance was set at $p < 0.05$.

For biomechanical data, there were 8 variables of interest including stance time, loading rate, and 6 peak forces (impact peak, active peak, breaking peak, propulsive peak, medial peak and lateral peak). A 2 (type of taping) × 3 (speed) Analysis of Variance (ANOVA) with repeated measure was performed for each of these variables to compare between the taping conditions and across the three speeds. In cases where Mauchley's test showed the violation of the sphericity assumption, Greenhouse-Geisser's epsilon adjustment was used. Bonferroni adjusted *post-hoc* comparisons were applied where necessary. Statistical significance was set at $p < 0.05$. Observed power and effect size (partial eta squared, η_p^2) were also calculated.

Results

In the comfort assessment, the VAS score was significantly lower in low-Dye taping than sham tape (low-Dye, 63.8 (24.3) mm, sham 122.0 (16.0) mm, mean difference [95% CI], -58.2 [68.2, 48.2] mm, p < 0.001).

For all biomechanical variables, there was a significant main effect of speed but no interaction effect or difference between the two taping conditions (Table 2). As running speed increased, there was a decrease in stance time (p < 0.001) and increase in loading rate (p = 0.009), impact peak (p = 0.004), active peak (p < 0.001), breaking peak (p < 0.001), propulsive peak (p < 0.001), medial peak (p < 0.001), and lateral peak (p < 0.001). Graphical comparison of the force-time histories over the stance phase of running revealed similar patterns between low-Dye and sham taping conditions (Figure 2).

Table 2. Stance time and ground reaction forces characteristics across 2 taping conditions and 3 speeds.

Variables	Speed (km/h)	Low-Dye Tape	Sham Tape	Difference [95%CI]	*p*-value Tape	*p*-value Speed	*p*-value Tape×Speed	Significant *post-hoc* differences
Stance Time (ms)	9	269.7(11.9)	267.9(16.8)	1.74(-4.07, 7.55)	0.053	**<0.001**	0.503	9 > 10
	10	259.3(12.1)	253.9(13.7)	5.40(0.34, 10.46)				9 > 11
	11	246.1(14.2)	242.7(11.9)	3.40(-1.72, 8.52)				10 > 11
Loading Rate (BW/s)	9	48.98(11.29)	47.65(14.14)	1.33(-3.33, 5.98)	0.363	**0.009**	0.421	11 > 9
	10	54.21(19.87)	54.72(18.79)	-0.51(-6.20,5.18)				
	11	63.47(25.70)	59.87(25.71)	3.60(-1.69, 8.89)				
Impact Peak (BW)	9	1.81(0.26)	1.89(0.37)	-0.078(-0.195, 0.040)	0.086	**0.004**	0.55	9 < 11
	10	1.86(0.33)	1.95(0.41)	-0.088(-0.198, 0.021)				10 <11
	11	1.99(0.33)	2.02(0.38)	-0.032(-0.121, 0.057)				
Active Peak (BW)	9	2.37(0.16)	2.41(0.17)	-0.037(-0.086, 0.011)	0.176	**<0.001**	0.159	9 < 11
	10	2.41(0.16)	2.44(0.17)	-0.036(-0.075, 0.002)				10 < 11
	11	2.48(0.17)	2.47(0.15)	0.008(-0.042, 0.058)				
Braking Peak (BW)	9	-0.40(0.06)	-0.41(0.07)	0.009(-0.006, 0.025)	0.208	**<0.001**	0.825	9<10
	10	-0.44(0.11)	-0.45(0.10)	0.009(-0.005, 0.023)				9<11
	11	-0.48(0.10)	-0.49(0.12)	0.004(-0.024, 0.033)				10 < 11
Propulsive Peak (BW)	9	0.26(0.03)	0.27(0.03)	-0.004(-0.015, 0.007)	0.294	**<0.001**	0.613	9<10
	10	0.29(0.03)	0.30(0.03)	-0.007(-0.013, -0.002)				9 <11
	11	0.33(0.03)	0.33(0.04)	-0.002(-0.018, 0.014)				10< 11
Medial Peak (BW)	9	0.31(0.08)	0.31(0.08)	0.001(-0.020, 0.023)	0.85	**<0.001**	0.158	9 <10
	10	0.33(0.08)	0.34(0.09)	-0.014(-0.041, 0.013)				9 <11
	11	0.36(0.08)	0.35(0.08)	0.007(-0.019, 0.033)				10 < 11
Lateral Peak (BW)	9	0.18(0.09)	0.15(0.09)	0.025(-0.002, 0.051)	0.063	**<0.001**	0.549	9 <10
	10	0.21(0.11)	0.19(0.12)	0.021(-0.013, 0.055)				9 <11
	11	0.24(0.15)	0.21(0.12)	0.034(-0.002, 0.071)				

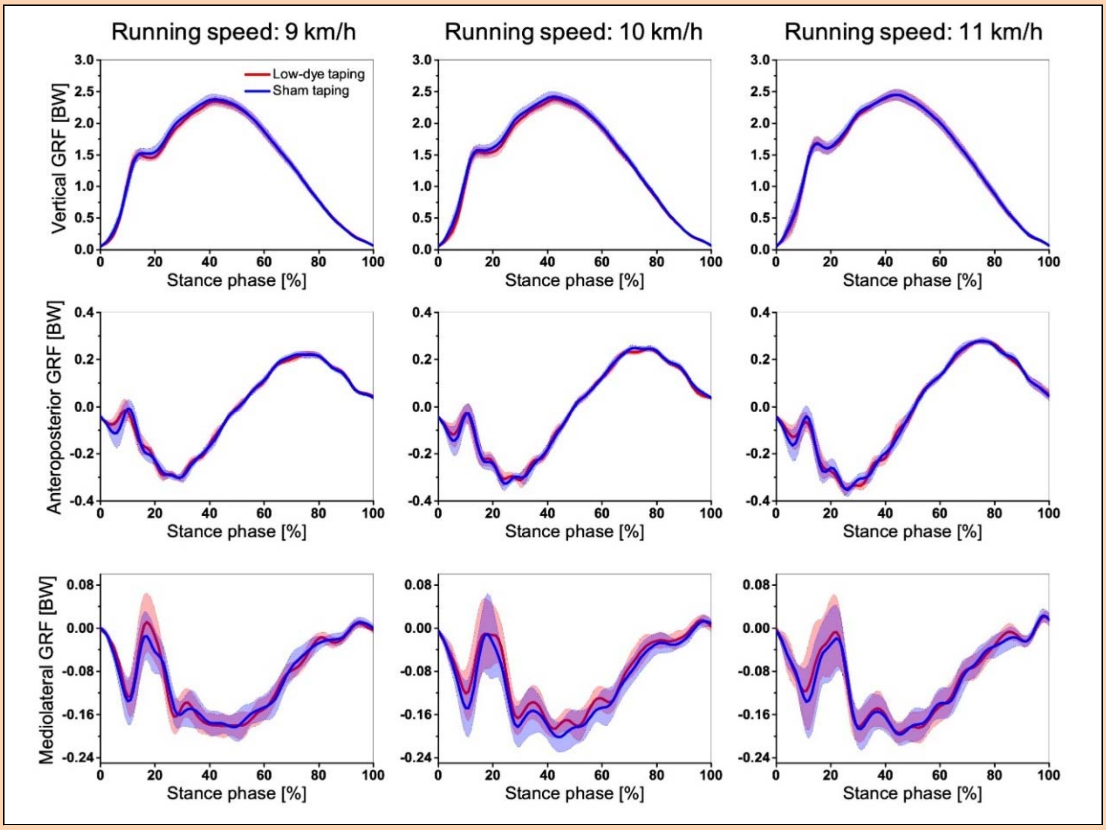

Figure 2. Mean ± 90% confidence intervals ensemble ground reaction force (GRF) time histories in vertical, anteroposterior, and mediolateral directions.

Discussion

This study investigated the effects of low-Dye taping on running biomechanics and comfort level in female recreational runners. The two findings were: (i) participants were less comfortable with the low-Dye taping technique when compared with sham taping, and (ii) application of low-Dye tape did not alter GRF variables during running.

Comfort level

As hypothesized, participants felt less comfortable when low-Dye taping was applied when compared with the sham condition. The discomfort is likely due to the restricted joint movements resulted from the tension of the tapes. The present findings are consistent with those reported by Hyland et al. (2006) that in general current taping methods are often uncomfortable. One study comparing different types of tapes found that rigid taping was ranked the least comfortable compared with barefoot and elastic taping (Smith et al., 2015). In the present study, rigid tape was used in both low-Dye and sham conditions, with variation in the application of force. The lower comfort rating in low-Dye taping may also be due to the greater surface area of the foot and force that the tape was applied when compared with the sham technique (Figure 1). It should be acknowledged that previous taping experience might influence the comfort level of taping. Through verbal confirmation before the beginning of running test, all the participants declared that they had no experience of low-Dye taping or other taping techniques. With reference to the 'preferred movement path' and 'comfort filter' paradigms for running injury prevention (Nigg et al., 2015), runners may benefit from choosing a comfortable taping method which allows them to remain their preferred running patterns. In the attempt to reduce foot pronation via taping, further development in taping material and technique may help improve the subjective comfort experienced by runners alongside anatomical and biomechanical considerations. As the optimal amount of foot pronation is yet to be established (Nigg et al., 2019), comfort perception should be an important consideration for athletes when selecting treatments to control rearfoot motion.

Biomechanical effect

To our best knowledge, this study is the first to identify that applying low-Dye taping does not change three dimensional GRF variables comparing with sham taping at a range of speeds in flat-footed female runners. The hypothesis that low-Dye taping would decrease loading during running is not supported since no difference in stance time, loading rate, or peak forces in any direction were found between sham taping and low-Dye taping. These results suggest that the external load, measured by GRF, were similar regardless of the taping technique. This study also showed the increase in running speed resulted in short stance time and greater loading rate and peak forces, which are largely consistent with previous studies (De Wit et al., 2000; Grabowski and Kram, 2008).

The lack of biomechanical differences between low-Dye and sham taping is in agreement with a recent study by Moore et al. (2020) which showed that external ankle taping did not alter GRF or lower extremity kinematics and kinetics during straight sprints in young males. Focusing on females, previous studies demonstrated that low-Dye taping was effective in increasing navicular height during quiet standing immediately after the application of tape (Ator et al., 1991; Vicenzino et al., 1997). Newell et al. (2015) investigated navicular height during running and showed no differences from baseline to post-tape for navicular height in the low-Dye and no-tape conditions. When the navicular height was significantly higher immediately after application of the navicular-sling condition, it was reduced after 5 minutes of treadmill running (Newell et al., 2015). Interestingly, another study also found that the corrective effect of raising the navicular height by taping greatly diminished after 10 minutes of jogging (Ator et al., 1991). Although these earlier studies only measured static navicular height and did not evaluate the dynamic loading response (Ator et al., 1991; Newell et al., 2015; Vicenzino et al., 1997), the reported short-lasting effect of taping could help explain the lack of biomechanical differences observed in the present study. When interpreting the initial correction of foot alignment via anti-pronation taping, caution should be taken not to assume that taping will be effective in restricting joint motion or reduce loading during exercise.

In studies where the foot-ground interface was modified via different footwear properties, runners were found to adjust their kinematics to maintain constant external loads such as peak forces and loading rate (Kong et al., 2009). It is possible that the participants in the present study have adjusted their running technique in response to taping such that similar GRF profiles are maintained. For example, greater knee flexion can be a strategy to regulate impact force (Bobbert et al., 1991) in order to compensate for the potentially increased impact magnitude caused by reduced foot pronation (Gerritsen et al., 1995). On the other hand, it has been reported that sprinting biomechanics including GRF, kinematics, and kinetics did not differ between ankle taping and control groups (Moore et al., 2020). Since kinematic data were not obtained in the present study, these speculations cannot be confirmed. Given that stance time did not differ between the two taping conditions, it is unlikely that substantial kinematic adaption would have occurred. Moving forward, future studies can include joint kinematic (e.g. angles) and kinetic (e.g. moments) measurements to allow a more comprehensive biomechanical analysis. Researchers can also include a 'no tape' condition in additional to 'sham taping' (Hyland et al., 2006) to provide a clear view of how taping can influence running biomechanics. For clinical application, the current study confirmed that application of low-Dye taping in flat-footed female runners would not lead to adverse kinetic effects such as increased peak force and loading rates.

Limitations

As the first attempt to examine the effect of taping on running biomechanics in females, typical GRF variables at a range of speeds were measured. While this is considered one step forward from static foot alignment during standing (Ator et al., 1991; Vicenzino et al., 1997), only kinetic data were collected from the instrumented treadmill. For a more in-depth biomechanical analysis, future studies can also include kinematics and joint kinetics to clarify whether runners have adapted their running techniques in response to taping. The second limitation was that only one type of tape and the low-Dye technique were used. For maintaining the navicular height, more rigid tape such as Leukotape may be more effective, however, caution should be taken since the comfort level might be compromised. Additional research is warranted to further investigate the possible influences of different taping materials and techniques. The third limitation was that the *a-priori* power analysis was performed based on a hypothetical large effect size (Ng et al., 2020) since there were no available studies on taping effects or running GRF in the literature. We may have over-estimated the effect size, resulting in recruiting too few participants and hence under-powered statistical analysis. Finally, this study focused on asymptomatic flat-footed female runners with no pre-existing condition or pain. Future studies can establish the effects of taping for treating running related conditions such as plantar fasciitis.

Conclusion

Compared with sham taping, the application of low-Dye taping led to a decrease in comfort level among flat-footed female runners. For running biomechanics, low-Dye tape did not alter stance time, loading rate, or peak forces across a range of running speeds from 9 to 11 km/h. Clinicians can be assured that application of low-Dye taping in flat-footed female runners would not lead to adverse kinetic effects such as increased peak force and loading rates.

Acknowledgements

This study was funded by the Nanyang Technological University under the Undergraduate Research Experience on CAmpus (URECA) programme. Dr. Wei-Hsiu Lin was supported by the Ministry of Education, Taiwan. The funding sources are not involved in the followings: study design; the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication. We would like to thank Ms. Marabelle Heng from Singapore General Hospital for her advice on foot type assessment, Ms. Yvonne Yap from National University Hospital for her guidance on taping technique, and Mr Jing Wen Pan for his help with editing and preparation of figures. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

References

Ator, R., Gunn, K., McPoil, T.G. and Knecht, H.G. (1991) The effect of adhesive strapping on medial longitudinal arch support before and after exercise. *The Journal of Orthopaedic and Sports Physical Therapy* **14,** 18-23.

Bandholm, T., Boysen, L., Haugaard, S., Zebis, M.K. and Bencke, J. (2008) Foot medial longitudinal-arch deformation during quiet standing and gait in subjects with medial tibial stress syndrome. *The Journal of Foot and Ankle Surgery* **47,** 89-95.

Bobbert, M.F., Schamhardt, H.C. and Nigg, B.M. (1991) Calculation of vertical ground reaction force estimates during running from positional data. *Journal of Biomechanics* **24,** 1095-1105.

Cavanagh, P.R. and Rodgers, M.M. (1987) The arch index: A useful measure from footprints. *Journal of Biomechanics* **20,** 547-551.

Cheung, R.T.H., Chung, R.C.K. and Ng, G.Y.F. (2011) Efficacies of different external controls for excessive foot pronation: A meta-analysis. *British Journal of Sports Medicine* **45,** 743-751.

Cheung, R.T.H. and Ng, G.Y.F. (2007) Efficacy of motion control shoes for reducing excessive rearfoot motion in fatigued runners. *Physical Therapy in Sport* **8,** 75-81.

Chiu, M.-C. and Wang, M.-J. (2007) The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking. *Gait & Posture* **25,** 385-392.

Christensen, B.H., Andersen, K.S., Pedersen, K.S., Bengtsen, B.S., Simonsen, O., Kappel, S.L. and Rathleff, M.S. (2014) Reliability and concurrent validity of a novel method allowing for in-shoe measurement of navicular drop. *Journal of Foot and Ankle Research* **7,** 12.

Clansey, A.C., Hanlon, M., Wallace, E.S. and Lake, M.J. (2012) Effects of fatigue on running mechanics associated with tibial stress fracture risk. *Medicine and Science in Sports and Exercise* **44,** 1917-1923.

De Wit, B., De Clercq, D. and Aerts, P. (2000) Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics* **33,** 269-278.

Ferber, R., Davis, I.M. and Williams, D.S. 3rd (2003). Gender differences in lower extremity mechanics during running. *Clinical Biomechanics,* **18**, 350-357.

Ferber, R., Kendall, K. D. and Farr, L. (2011). Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. *Journal of Athletic Training* **46**, 142-149.

Franettovich, M., Chapman, A., Blanch, P. and Vicenzino, B. (2008) A physiological and psychological basis for anti-pronation taping from a critical review of the literature. *Sports Medicine* **38,** 617-631.

Gerritsen, K.G., van den Bogert, A.J. and Nigg, B.M. (1995) Direct dynamics simulation of the impact phase in heel-toe running. *Journal of Biomechanics* **28,** 661-668.

Gijon-Nogueron, G. and Fernandez-Villarejo, M. (2015) Risk factors and protective factors for lower-extremity running injuries: A systematic review. *Journal of the American Podiatric Medical Association* **105,** 532-540.

Grabowski, A.M. and Kram, R. (2008) Effects of velocity and weight support on ground reaction forces and metabolic power during running. *Journal of Applied Biomechanics* **24,** 288-297.

Hennig, E.M. (2001). Gender differences for running in athletic footwear. In: *Proceedings of the 5th Symposium on Footwear biomechanics, Zurich, Switzerland*, Hennig, E.M. and Stacoff, A., Eds, Zurich, Switzerland, pp. 44-45.

Huang, C.K., Kitaoka, H.B., An, K.N. and Chao, E.Y. (1993) Biomechanical evaluation of longitudinal arch stability. *Foot & Ankle* **14,** 353-357.

Hyland, M.R., Webber-Gaffney, A., Cohen, L. and Lichtman, P.T.S.W. (2006) Randomized controlled trial of calcaneal taping, sham taping, and plantar fascia stretching for the short-term management of plantar heel pain. *The Journal of Orthopaedic and Sports Physical Therapy* **36,** 364-371.

Kelly, L.A., Racinais, S., Tanner, C.M., Grantham, J. and Chalabi, H. (2010) Aumented low dye taping changes muscle activation patterns and plantar pressure during treadmill running. *Journal of Orthopaedics and Sports Physical Therapy* **40***,* 649-655.

Kluitenberg, B., Bredeweg, S.W., Zijlstra, S., Zijlstra, W. and Buist, I. (2012) Comparison of vertical ground reaction forces during overground and treadmill running. A validation study. *BMC Musculoskeletal Disorders* **13,** 235.

Kong, P.W., Candelaria, N.G. and Smith, D.R. (2009) Running in new and worn shoes: a comparison of three types of cushioning footwear. *British Journal of Sports Medicine* **43,** 745-749.

Milgrom, C., Finestone, A., Segev, S., Olin, C., Arndt, T. and Ekenman, I. (2003) Are overground or treadmill runners more likely to sustain tibial stress fracture? *British Journal of Sports Medicine* **37**, 160-163.

Mills, K., Blanch, P. and Vicenzino, B. (2010) Identifying clinically meaningful tools for measuring comfort perception of footwear. *Medicine and Science in Sports and Exercise* **42,** 1966-1971.

Mohr, M., Meyer, M., Nigg, S. and Nigg, B. (2017) The relationship between footwear comfort and variability of running kinemaitcs, *Footwear Science* **9**, 45-47.

Moore, C., Donovan, L., Murray, A.M., Armstrong, C. and Glaviano, N.R. (2020) External ankle taping does not alter lower extremity side-step cut and straight sprint biomechanics in young adult

males. *Sports Biomechanics* **19,** 395-410.
Mündermann, A., Stefanyshyn, D.J. and Nigg, B.M. (2001) Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Medicine and Science in Sports and Exercise* **33,** 1939-1945.
Murley, G.S., Menz, H.B. and Landorf, K.B. (2009) A protocol for classifying normal- and flat-arched foot posture for research studies using clinical and radiographic measurements. *Journal of Foot and Ankle Research* **2,** 22.
Napier, C., MacLean, C.L., Maurer, J., Taunton, J.E. and Hunt, M.A. (2018) Kinetic risk factors of running-related injuries in female recreational runners. *Scandinavian Journal of Medicine & Science in Sports* **28,** 2164-2172.
Newell, T., Simon, J. and Docherty, C.L. (2015) Arch-taping techniques for altering navicular height and plantar pressures during activity. *Journal of Athletic Training* **50,** 825-832.
Ng, J.W., Chong, L.J.Y., Pan, J.W., Lam, W.K., Ho, M., and Kong, P.W. (2020) Effects of foot orthosis on ground reaction forces and perception during short sprints in flat-footed athletes. *Research in Sports Medicine.* Online ahead of print.
Nigg, B.M., Baltich, J., Hoezer, S. and Enders, H. (2015). Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter'. *British Journal of Sports Medicine* **49,** 1290-1294.
Nigg, B., Behling, A. and Hamill, J. (2019) Foot pronation. *Footwear Science* **11**, 131-134.
Nolan, D. and Kennedy, N. (2009) Effects of low-Dye taping on plantar pressure pre and post exercise: An exploratory study. *BMC Musculoskeletal Disorders* **10,** 40.
Sell, K.E., Verity, T.M., Worrell, T.W., Pease, B.J. and Wigglesworth, J. (1994) Two measurement techniques for assessing subtalar joint position: A reliability study. *The Journal of Orthopaedic and Sports Physical Therapy* **19,** 162-167.
Smith, M.F., Coates, S., Leung, F. and Creaby, M. (2015) A comparison of rigid and elastic anti-pronation taping on foot posture and mobility in females with exercise related leg pain. *Journal of Science and Medicine in Sport* **19,** e24.
Stefanyshyn, D.J., Stergiou, P., Nigg, B.M., Rozitis, A.I. and Goepfert, B. (2003) Do females require different running footwear. In: *Proceedings of the Sixth Symposium on Footwear Biomechanics*, Queenstown, New Zealand, pp. 91-92.
Tong, J.W.K and Kong, P.W. (2016) Medial longitudinal arch development of children aged 7 to 9 years: A longitudinal investigation. *Physical Therapy,* **96**, 1216-1224.
Vicenzino, B., Feilding, J., Howard, R., Moore, R. and Smith, S. (1997) An investigation of the anti-pronation effect of two taping methods after application and exercise. *Gait & Posture* **5,** 1-5.
Videbaek, S., Bueno, A.M., Nielsen, R.O. and Rasmussen, S. (2015) Incidence of running – related injuries per 1000h of running in different types of runners: A systematic review and meta-analysis. *Sports Medicine* **45,** 1017-1026.

Key points

- Female flat-footed runners were less comfortable with low-Dye taping than sham taping.
- Stance time, peak forces, and vertical loading rate did not differ between low-Dye and sham taping.
- There was no beneficial or detrimental effect of low-Dye taping across a range of running speeds (9 to 11 km/h).

AUTHOR BIOGRAPHY

Hui Li Alvina KOH
Employment
Student Teacher at the National Institute of Education, Singapore
Degree
Bachelor of Science (Sport Science and Management)
Research interests
Sport biomechanics, sport taping
E-mail:
koh_hui_li_alvina@moe.edu.sg

Wei-Hsiu LIN
Employment
Associate Professor of the Department of Physical Education, Health and Recreation, National Chiayi University, Taiwan
Degree
PhD
Research interests
Sport biomechanics, injury prevention and rehabilitation, postural control
E-mail: whlin@mail.ncyu.edu.tw

Pui Wah KONG
Employment
Associate Dean (Office of Graduate Studies and Professional Learning), Associate Professor (Physical Education and Sports Science Academic Group), National Institute of Education, Nanyang Technological University, Singapore
Degree
PhD
Research interests
Sports and clinical biomechanics
E-mail: puiwah.kong@nie.edu.sg

✉ **Pui Wah Kong**
Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616