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Original Article

**Comparison of skin and shoe marker placement on metatarsophalangeal joint
kinematics and kinetics during running**

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Abstract:

This study investigated the effects of marker placement (skin- vs shoe-mounted) on metatarsophalangeal joint (MTP) kinematics and kinetics during running. Fifteen trained men ran on a 15-m track at 10 and 13 km/h with three (low, standard and high stiffness) shoe longitudinal bending stiffnesses (LBS). Reflective markers were fixed on the shoe upper, and on the skin using holes cut in the shoe. Three-dimensional marker positions and ground reaction forces were recorded at 200 and 2,000 Hz, respectively. Kinematic and kinetic parameters were analyzed using one-dimensional metrics (statistical parametric mapping). MTP joint was less dorsiflexed at midstance ([57% to 100%] of braking phase and [0% to 48%] of pushing phase), and the MTP joint plantarflexion moment was higher ([22% to 55%] of pushing phase) with the shoe markerset in comparison with the skin markerset. The effect of LBS on MTP angle was found to be significant for a larger percentage of each stride using the shoe markerset compared to the skin markerset. However, the effect of LBS on plantarflexion moment was significant with the shoe markerset only. The effect of running speed on MTP angle was significant for a larger percentage of each stride with the skin markerset. This study demonstrates that the placement of markers influences the measurement of MTP kinematics and kinetics and that these effects are mediated by other variables such as LBS or running speed. It is concluded that the shoe markerset does not fully reflect the movement of the MTP joint.

1. Introduction

Motion capture systems and force plates are standard tools used to measure joint kinematics and kinetics with applications in sports medicine and sports performance. Biomechanical studies commonly focus on ankle, knee and hip kinematics to describe locomotion, considering the foot as a unique segment. The rearfoot and the metatarsophalangeal joint (MTP) are usually

neglected as they contribute little to the running propulsion. Although some studies have highlighted the elastic energy-saving characteristics of the foot (Ker et al., 1987; Stearne et al., 2016), only 0.5 to 2% of the whole-body's positive work is produced by the MTP joint (Cigoja et al., 2019; Hoogkamer et al., 2018). The actual role of foot motion has been reassessed with the advent of carbon plate inserts in racing shoes due to the perturbation induced by the plate on the MTP joint (Hoogkamer et al., 2018; Roy & Stefanyshyn, 2006; Stefanyshyn & Nigg, 1997).

Two types of marker placements can be used for non-invasive estimation of in-shoe joint kinematics – as MTP joint and rearfoot kinematics – using motion capture. The simplest is to fix markers directly on the shoe sole or upper, as in seminal studies analyzing MTP joint motion (Stefanyshyn & Nigg, 1997). A more precise method involves fixing the markers directly on the skin, using holes or 'windows' made in the shoe upper (for a review, see Arnold & Bishop, 2013). Previous research suggests that these two placements do not yield the same results regarding rearfoot kinematics. Some studies have shown that shoe markersets significantly underestimated i) the calcaneus range of motion (ROM) across all planes of motion (Alcantara et al., 2018; Trudeau et al., 2017), and ii) the external rotation velocity and peak ankle eversion velocity (Sinclair et al., 2013), concluding that the rearfoot moves inside the shoe. Prior investigations also showed that shoe markersets over-estimate foot pronation (Stacoff et al., 1992), eversion, and tibio-calcaneal rotation across all planes (Reinschmidt et al., 1997), suggesting that shoe markersets do not only measure foot kinematics but also the deformation of the shoe (Reinschmidt et al., 1997). Overall, this suggests that foot motion may not be accurately captured by measuring shoe motion. However, to our knowledge, no study has compared the effect of marker placement (foot vs shoe) on the measurement of MTP joint movement during running.

The effect of varying longitudinal bending stiffness (LBS) on MTP joint has been investigated using either skin markersets (Cigoja et al., 2019, 2020, 2021; Day & Hahn, 2021; Flores et al., 2019; Oh & Park, 2017; Willwacher et al., 2013, 2014), or shoe markersets (Beck et al., 2020; Farina et al., 2019; Healey & Hoogkamer, 2022; Hoogkamer et al., 2018; Madden et al., 2016; Roy & Stefanyshyn, 2006; Stefanyshyn & Nigg, 1997). Overall, higher LBS reduces dorsiflexion of the MTP joint (Day & Hahn, 2021; Healey & Hoogkamer, 2022; Hoogkamer et al., 2018; Madden et al., 2016; Oh & Park, 2017; Willwacher et al., 2013), reduces MTP joint dorsiflexion angular velocity (Day & Hahn, 2021; Healey & Hoogkamer, 2022; Hoogkamer et al., 2018; Willwacher et al., 2013), decreases MTP joint negative work (W^-) (Cigoja et al., 2019; Day & Hahn, 2021; Farina et al., 2019; Healey & Hoogkamer, 2022; Hoogkamer et al., 2018), and increases positive work (W^+) (Cigoja et al., 2019, 2020; Willwacher et al., 2013). Although similar conclusions might seem to be drawn from the two methods regarding changes in LBS, a direct comparison of the two methods still remains to be done. Additionally, MTP joint biomechanics are also affected by running speed: MTP joint is more involved when we go faster with an increase of MTP joint range of motion, maximal plantarflexion moment, and moment at time of peak dorsiflexion (Day & Hahn, 2019b). Yet, it is not known whether the effect of running speed on MTP joint kinematics and kinetics is consistent across the two marker placements (Day & Hahn, 2019; Day & Hahn, 2021; Flores et al., 2019).

The present study aimed to compare MTP joint kinematics and kinetics during running using skin vs shoe markersets at various LBSs and speeds, to determine whether these two methods could be used interchangeably. We hypothesized that the shoe markerset would not represent MTP joint kinematics and kinetics as accurately as the skin markerset. We also hypothesized that the direction of changes elicited by both LBS and running speed would be similar across markersets, i.e. there would be no effect of marker placement on the interpretation of the influence of LBS and running speed on MTP joint biomechanics.

Journal Pre-proofs

2. Methods

Participants

Fifteen recreational male runners were recruited (age 25 ± 5 years, mass 74.3 ± 6.9 kg, height 1.77 ± 0.06 m). They were all rearfoot strikers and free from lower limb injury in the past six months. They provided their written informed consent, in accordance with the Declaration of Helsinki prior to the experiment.

Experimental design

Participants initially ran on a treadmill for 5 min at their preferred running speed for warm up and shoe familiarization purposes (Divert et al., 2005) for each of the three shoe conditions (HIGH: high stiffness; STA: standard stiffness; LOW: low stiffness). Participants then performed 5 trials on a 15-m runway at two different speeds (10 and 13 km/h) for each shoe condition. Running speed was measured using photocells (Whitty Tab, Microgate, Mahopac, NY) placed at the beginning and at the end of the measurement area at $\frac{2}{3}$ of the runway. A trial was considered valid if actual speed was within $\pm 5\%$ of the required speed. Ground reaction forces (GRF) were measured at 2,000 Hz using six force platforms (Kistler, Winterthur, Switzerland) embedded in the runway. Kinematics were recorded at 200 Hz using a motion capture system with 12 optoelectronic cameras (Motion analysis corporation, Raptor 4, Santa Rosa, California) tracking the position of 27 markers placed on the right lower limb of the participants using the markerset described in Besson et al. study (2019) for all markers proximal to the ankle. To measure MTP joint motion, 6 markers were placed on the first and fifth metatarsals, on the hallux and on the posterior, medial and lateral faces of the calcaneus, using holes cut in the shoe (skin markerset, abbreviated FTM for “foot markerset”), in accordance with Bishop et al., (2015) and Shultz & Jenkyn (2012). To measure simultaneously FTM and Shoe-mounted markers (shoe markerset: SHM), SHM were fixed on the shoe upper just below each hole (Figure 1), and were therefore not placed perfectly on the anatomic landmark, but

very precisely and accurately placed to respect the alignment of the MTP and avoid shift between foot and shoe MTP joint axis.

INSERT FIGURE 1 NEAR HERE

Shoe conditions

Three visually similar shoe prototypes differing exclusively in LBS were used in the study. The standard shoe had an intermediate level of LBS (STA: 8.4 N/mm), a model with 9 mm grooves cut on the forepart of the midsole provided a lower LBS (LOW: 5.1 N/mm) and a model with a carbon plate embedded between the midsole and the outsole provided a higher LBS (HIGH: 16.2 N/mm). A bespoke three-point flexion test was used to measure shoe LBS without the contribution from the shoe upper, using a frame supporting the shoe on 70% of the length of the sole, and a slow compression dynamometer bending the sole at 1 mm/s until a 5 mm displacement was achieved. For the comparison with other studies, one should be aware that with the addition of the shoe upper, the LBS can be considered slightly greater than the reported values (Fraser et al. 2014). Force was measured at the stabilization point, and then released at 1 mm/s. Measurements were repeated 3 times over 5 consecutive cycles for each shoe and averaged to obtain the LBS of each shoe.

Data Analysis

Visual3D software (C-Motion, Germantown, Maryland) was used to compute MTP joint angle, angular velocity and moment on the sagittal plane. Kinematic marker trajectories and GRF data were low-pass filtered at 30 Hz using a zero-lag 4th order Butterworth.

Stance phase was detected using a 30 N threshold on the vertical component of the GRF. It has been shown that LBS variation induces different distribution of the braking and pushing phases (Willwacher et al., 2013). As we planned to conduct curve analyses using statistical parametric mapping (SPM), we divided the trajectory between braking and pushing phase according to the

negative and positive part of the anteroposterior component of the GRF, respectively. This allowed us to avoid temporal shifts between the different phases within the analyzed curves. Each phase was time normalized from 0-100%. MTP joint was modeled as an oblique axis from the first to the fifth metatarsal (Smith et al., 2012). The joint center was non-fixed, perpendicular to the center of pressure (COP) (Day & Hahn, 2019a). MTP joint movement was defined as the movement of the hallux around the MTP joint axis in the rearfoot coordinate system. MTP joint moment, power, and work were studied only during the period of the stance phase when the COP was ahead of the MTP joint axis on the transverse plane, that we called MTP joint pushing time (Day & Hahn, 2019). Negative (W^-) and positive MTP joint work (W^+) were calculated as the integral of the negative and positive parts of the MTP joint power curve, respectively. The MTP joint movement variability was assessed by calculating, for each condition, the standard deviation of the 5-trials for minimal and maximal dorsiflexion angle ($^\circ$) during stance phase.

Statistics

Zero-dimensional analyses were performed on Rstudio (R-Studio Inc., Boston, Massachusetts), for minimal, maximal, and mean values of MTP joint angle, angular velocity, angular moment, positive and negative work, and MTP joint movement variability using the mean value of the five trials for each participant and condition. Normality was checked using Shapiro-Wilk tests. Three-way repeated-measures ANOVA (markerset \times speed \times LBS), followed when applicable by Bonferroni post-hoc tests, were performed to compare the markerset effect and interactions. Effect sizes were evaluated using partial eta-squared (η_p^2) and interpreted according to Cohen's scale (small effect: $0.01 < \eta_p^2 < 0.06$; moderate effect: $0.06 < \eta_p^2 < 0.14$; large effect: $\eta_p^2 > 0.14$, Cohen, 1988).

Curve analyses with 1-D statistical parametric mapping (SPM) of the entire kinematics and kinetics time series were performed using Matlab (The Matworks, Natick, Massachusetts) and

the open-source spm1d code (www.spm1d.org, Pataky et al., 2015). Data normality was checked with the d'Agostino test. SPM three-way repeated-measures ANOVA (markerset \times speed \times LBS), followed when applicable by Bonferroni post-hoc tests, were performed to compare the markerset effect and interactions. The permutation method was applied to SPM ANOVA if normality assumptions were not met. SPM two-way repeated-measures ANOVA (speed \times LBS) were computed for each markerset, followed when applicable by Bonferroni post-hoc tests. Alpha level was set at 0.05.

3. Results

One participant was excluded from the analysis as shoe and skin marker trajectories could not be accurately distinguished during the reconstruction process. Therefore, data from 14 subjects were analyzed.

Markerset influence on MTP joint kinematics and kinetics

Contact, braking, and pushing durations and MTP joint pushing duration are presented in Table 1. There was a significant markerset effect on MTP joint pushing duration ($F=86.4$; $p<0.001$; $\eta_p^2=0.87$). MTP joint pushing duration was $4.5 \pm 1.0\%$ higher using skin markerset (FTM) than using shoe markerset (SHM). There was also a significant effect of speed on MTP joint pushing duration ($F=89.6$; $p<0.001$; $\eta_p^2=0.87$), with higher speed leading to shorter MTP pushing duration. There was no significant interaction between LBS, speed and markerset on MTP joint pushing duration.

INSERT TABLE 1 NEAR HERE

There was a main effect of markerset on MTP joint angle during the second half of the braking phase [57 to 100%] and the first half of the pushing phase [0 to 48%] (*Figure 2A*). MTP joint angle was higher during peak plantar flexion of the stance (around midstance) phase when

calculated from SHM compared to FTM ($+3.5 \pm 4.2^\circ$, $p < 0.001$, $\eta_p^2 = 0.60$). None of the markerset \times speed, markerset \times LBS and markerset \times speed \times LBS interactions were significant for MTP joint angle (respectively $F=4.2$, $p=0.14$; $F=1.4$, $p=0.51$; $F=2.2$, $p=0.36$). There was a main effect of markerset on MTP joint plantarflexion moment (*Figure 2B*), which was higher with SHM compared to FTM between 22 and 55% of the moment production phase, with a $7 \pm 11\%$ higher peak value ($p < 0.001$, $\eta_p^2 = 0.33$). There were significant markerset \times LBS and markerset \times speed interactions at the end of the phase (respectively [88 to 100%], $F=30.5$, $p=0.009$, and [67 to 100%], $F=115$, $p < 0.001$). There was a significant main effect of markerset on minimal MTP joint dorsiflexion angle variability ($F=11.7$, $p=0.005$, $\eta_p^2 = 0.47$), which was higher with FTM than SHM (1.29 ± 1.30 vs $0.77 \pm 0.63^\circ$). There was no significant main effect of markerset on maximal MTP joint dorsiflexion angle variability ($F=0.8$, $p=0.392$, $\eta_p^2 = 0.06$, FTM: $1.51 \pm 1.24^\circ$; SHM: $1.38 \pm 0.84^\circ$). None of the markerset \times speed, markerset \times LBS and markerset \times speed \times LBS interactions were significant for both minimal and maximal joint dorsiflexion angle variability.

INSERT FIGURE 2 NEAR HERE

Markerset influence on the effect of LBS

The main effect of LBS on the MTP joint angle was significant with SHM ($p < 0.05$ [0 to 83%] of braking phase and [43 to 100%] of pushing phase) and with FTM (respectively [9 to 23%] and [88 to 100%] of braking and pushing phases). A higher dorsiflexion angle was observed with increased LBS (*Figure 3A*). The LBS effect on peak MTP joint dorsiflexion angle was significant with SHM ($F=34.92$, $p < 0.001$, $\eta_p^2 = 0.73$), but not with FTM ($F=3.12$, $p=0.061$, $\eta_p^2 = 0.19$). There was a significant main effect of LBS on MTP joint moment only with SHM and at the end of pushing phase ([65 to 99%]). Higher LBSs yielded higher plantarflexion moments (*Figure 3B*).

INSERT FIGURE 3 NEAR HERE

Markerset influence on the effect of running speed

The effect of speed on MTP joint angle was significant with both markersets in the braking phase (FTM: [39 to 100%], SHM: [0 to 21%] and [40 to 78%]). During the pushing phase, the effect of speed on MTP joint angle was only significant with FTM ([51 to 85%], Figure 4A). The effect of speed on MTP joint moment was significant over a large part of the stance phase, independently of the markerset ([2 to 92%] for FTM; [2 to 80%] for SHM, Figure 4B).

INSERT FIGURE 4 NEAR HERE

4. Discussion

This study is the first to investigate MTP joint markers position during running. The primary aim was to compare MTP joint kinematics and kinetics between shoe- and skin-mounted markers during running. We hypothesized that the shoe markerset would not represent the movement of the MTP joint as accurately as the skin-mounted markerset. The main results of this study are that, as compared to skin markerset, shoe markerset overestimated plantarflexion angle at midstance, and peak dorsiflexion moment. The second aim of this study was to investigate the influence of marker placement on the effects of LBS and running speed. We hypothesized that the interpretation of LBS and speed effects would be similar between markersets. Our results do not support this hypothesis as the effects of LBS and speed were dependent on the markerset. For instance, the effect of LBS on MTP joint moment was only significant with the shoe-mounted markerset.

Markerset influence on MTP joint kinematics and kinetics

This study provides evidence that SHM are not representative of MTP joint motion measured using FTM, peak plantarflexion angle and moment were overestimated, compared to FTM. Such large effects of markerset on MTP joint kinematics and kinetics can be explained by the

movement of the foot inside the shoe, and by the additional deformation of the shoe measured with SHM. For instance, we found that MTP joint measurements using SHM were less dorsiflexed than with FTM at midstance (during peak plantarflexion). This difference could originate i) from the slight depression of the metatarsals at midstance pressing in the compliant shoe insole and thereby limiting MTP joint plantarflexion, and ii) in shoe upper overflexion at midstance (Miura et al., 2019). Combined, these results indicate that peak plantarflexion may be overestimated with SHM. After midstance, the difference between markersets ceases to be significant as the COP continues to move forward of the MTP joint towards the toes. Overestimation of the MTP joint peak plantarflexion moment by SHM can be explained by differences in MTP joint angle measurements between markersets. The MTP joint lever arm is inversely related to MTP joint dorsiflexion angle. A reduced MTP joint dorsiflexion with SHM implies that a higher MTP joint plantarflexion moment is required to overcome the increased lever arm. Differences in joint moment, and angular velocity (Appendix 1) between markersets led to a markerset effect on the measurement of negative and positive work (Appendix 2). With SHM, the higher dorsiflexion velocity (see Appendix 1. Figure 1) associated with higher plantarflexion moment during the pushing phase led to overestimating W^- compared to FTM. At the end of the stance phase, when MTP joint is plantarflexing (approximately 90 to 100% of stance phase), SHM W^+ was underestimated because plantarflexion velocity was lower than with FTM and the plantarflexion moment was similar to FTM.

The shorter MTP joint pushing duration measured using SHM may be due to a backward shift of the foot inside the shoe during running compared to the static standing position, creating a misalignment between MTP joint axes measured with skin or shoe markersets.

Finally, MTP joint angle variability was noticeably lower with SHM than FTM (see Figure 2), especially at midstance (when dorsiflexion angle reaches its minimum). Specifically, the foot appears to move significantly more from trial to trial than the shoe. This could be explained by

the foot movement inside the shoe which is not recorded with SHM. In this sense, reducing the movement variability by using SHM could artificially increase the statistical power compared to the same analysis performed using FTM, suggesting that MTP joint kinematics and kinetics should ideally be measured on the skin and not on the shoe, to be more in line with real foot motion.

Markerset influence on the effect of running speed and LBS

Increases in running speed led to higher MTP joint dorsiflexion, higher angular velocities and joint moments in the current study, as it has previously been shown in the literature (Day & Hahn, 2019b, 2021; Flores et al., 2019; Fu et al., 2021), showing that the involvement of the MTP joint is higher when running speed increase (Day & Hahn, 2019b). Our findings indicate that the effect of speed on MTP joint moment is similar using either FTM or SHM, but the magnitude of the effect when studying MTP joint angle is greater with FTM, especially at midstance and during the pushing phase. This difference can be due to the slight depression of the metatarsals in the compliant midsole at midstance which may be greater at higher speeds due to higher ground reaction forces (Fu et al., 2021; Nigg et al., 1987). Therefore, the increased dorsiflexion at midstance at 13 compared to 10 km/h was only detected with FTM.

Both markersets showed that increased LBS reduced MTP joint dorsiflexion, increased contact time, pushing time, in line with the literature (Hoogkamer et al., 2018; Madden et al., 2016; Oh & Park, 2017; Rodrigo-Carranza et al., 2021; Willwacher et al., 2013). However, our findings indicate that the effects of LBS on MTP joint kinematics and kinetics depend on the markerset placement. Indeed, the LBS effect i) was significant for the MTP joint angle for a longer relative duration of the stance phase when using SHM vs FTM, ii) was significant for the MTP joint moment with SHM only. It has previously been shown that a higher LBS led to lower MTP joint peak dorsiflexion angle during propulsion (because the shoe is harder to bend) with both SHM (Hoogkamer et al., 2018; Madden et al., 2016) and FTM (Oh & Park, 2017; Willwacher

et al., 2013). Our results showed an effect of LBS for a longer relative duration with SHM compared to FTM, with a significant LBS effect on peak dorsiflexion angle detected only with SHM. Such differences between markersets could be due to: i) the larger angle variability when measured with FTM, which could affect the detection of a statistical effect, ii) the higher shoe deformation compared to foot deformation with increased LBS. However, Oh & Park (2017) and Willwacher et al. (2013) detected LBS effect on peak dorsiflexion with FTM, but the range of LBS used on these studies is larger than in the present study, with carbon plate thickness two times that of the highest shoe LBS in this study.

Overall, differences between markersets are important enough to lead to different conclusions when comparing LBS. Even if the effect of LBS on contact and pushing duration, and dorsiflexion velocity were not different between markersets, SHM was more sensitive to changes in MTP joint dorsiflexion and joint moment as a function of LBS than FTM. Caution is therefore advised when interpreting LBS effects using shoe markersets as the actual motion of the foot may be occluded.

One limitation of the present study is that SHM could not be placed exactly on the same anatomical landmarks as the skin markerset and were placed just below. One cannot rule out the fact that it may induce some discrepancies with the perfect anatomical position (McDonald et al., 2019). However, it was postulated that the movement of the foot inside the shoe was more determinant of the markerset differences. Moreover, this study design was preferred over performing separate trials, as it allowed comparing shoe and skin markersets during the same running strides and avoided repeating running trials that may add variability (Mann et al., 2015). Our three-way repeated-measures ANOVA was underpowered to detect Markerset \times LBS \times speed interactions due to a small sample size. Even if it is not the center of our analysis, interactions part of the results should be taken with caution. For clarity, the effect of using three-way instead of a two-way repeated measures ANOVA is discussed in Appendix D. Our results

are similar between the two analyses (three vs. two-factor RMANOVAs). Therefore, our interpretation and discussion are valid.

5. Conclusion

Our results indicate that markers fixed on the external surface of the shoe vs directly on the skin are not interchangeable for the measure of MTP joint kinematics and kinetics. Shoe markersets do not reflect the movement of the foot inside the shoe as it cannot detect the slight sliding of the MTP joint into the midsole at midstance, and the effects of LBS and speed on MTP joint kinematics were found to be dependent on the markerset used. Although the skin markerset increased variability, it allowed measuring actual foot motion independent of shoe deformation. Therefore, we recommend using skin markersets when possible, especially when the aim of the study is to analyze LBS. Furthermore, when appraising the contribution of previous literature relating the effects of LBS on running biomechanics, attention must be given to the methodologies that were used.

6. Conflict of interest statement

No potential conflict of interest was reported by the authors.

7. Acknowledgements

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FIGURES CAPTIONS

Figure 1. Markerset on the skin and on the shoe (blue circles: skin-mounted markers; white circles: shoe-mounted markers)

Figure 2. MTP joint angle during stance phase (panel A) and MTP joint moment during pushing phase (panel B) with shoe markerset (SHM) or skin markerset (FTM) for all speed and LBS conditions averaged. Greyed area represent periods of significant markerset effects (SPM ANOVA). Dotted black vertical line separates braking and pushing phases.

Figure 3. MTP joint angle (panel A) and joint angular moment (panel B) with shoe markerset (SHM) or skin markerset (FTM) for each LBS. Black horizontal bars denote periods of significant effects of LBS. Dotted black vertical line separates braking and pushing phases. HIGH: high stiffness; STA: standard stiffness; LOW: low stiffness.

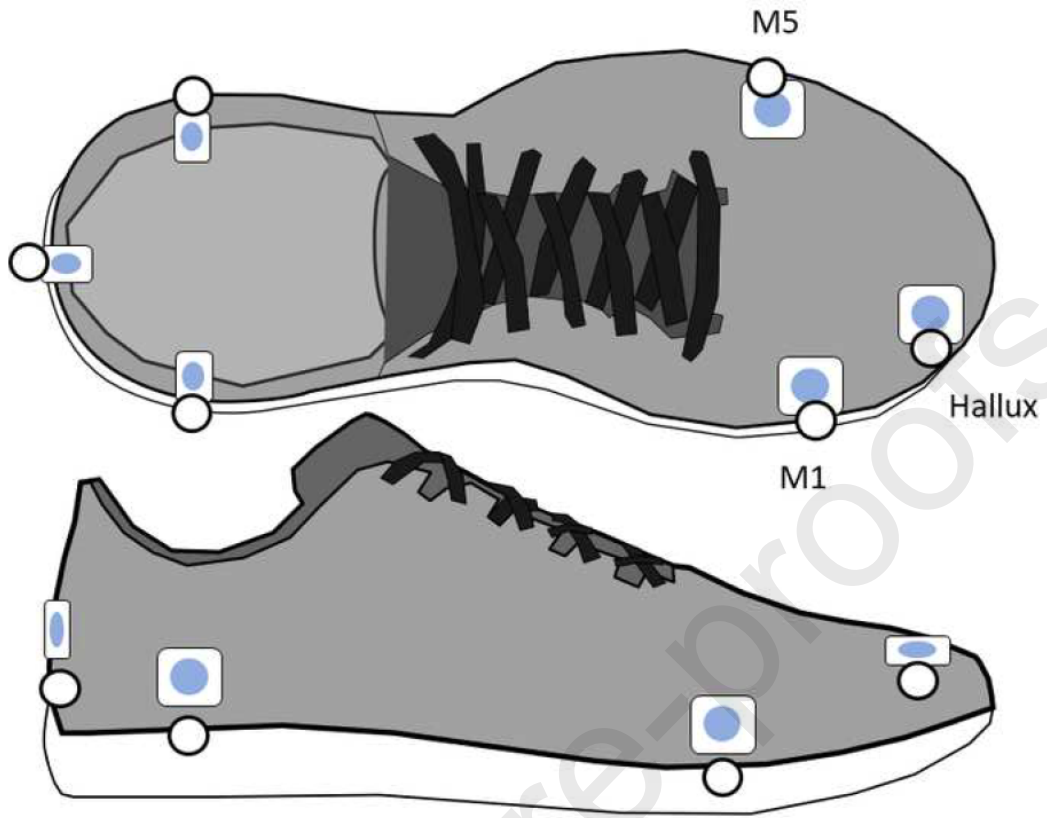
Figure 4. MTP joint angle (panel A) and joint angular moment (panel B) with shoe markerset (SHM), or skin markerset (FTM) for each speed. Black horizontal bars denote periods of significant effects of speed. Dotted black vertical line separates braking and pushing phases (10: 10 km/h; 13: 13 km/h).

Table 1. Mean values \pm standard deviations for the duration of each part of the contact duration measured for all speed and LBS conditions.

	Speed (km.h ⁻¹)	LBS			LBS effect		Speed effect	
		LOW	STA	HIGH	P	η_p^2	P	η_p^2
Contact duration (ms)	10	268 \pm 17	268 \pm 17	272 \pm 14	*	0.24	***	0.97
	13	233 \pm 14	234 \pm 13	236 \pm 14				

Braking duration (ms)	10	132 ± 9	133 ± 10	131 ± 9	n.s	0.04	***	0.89
	13	118 ± 7	118 ± 9	118 ± 7				
Pushing duration (ms)	10	135 ± 12	135 ± 11	141 ± 9	**	0.47	***	0.98
	13	115 ± 10	116 ± 8	118 ± 10				
FTM MTP pushing duration (ms)	10	126 ± 13	123 ± 22	128 ± 16	n.s	0.23	***	0.87
	13	105 ± 10	103 ± 13	107 ± 11				
SHM MTP pushing duration (ms)	10	130 ± 14	128 ± 23	136 ± 16	Markerset effect: p<0.001; $\eta_p^2=0.87$			
	13	110 ± 11	109 ± 13	114 ± 12				

SHM: Shoe markerset; FTM: skin markerset; LOW: low LBS; STA: standard LBS; HIGH: high LBS; P: p-value; η_p^2 : Partial eta-squared; n.s: non-significant; * indicates a significant main effect of the Anova, *: p<0.05, **: p<0.01, *** p<0.001.



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