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Revisión

Effect of shoe drop on running and walking biomechanics: a systematic review

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ABSTRACT

Objective: The aim of this review is to examine the biomechanical effect of the shoe drop on the kinematic, kinetic and spatiotemporal variables in running and walking.
Method: The search engine and databases used were Mendeley, Pubmed, World Wide Science and Science Direct, between the dates of January 2010 to December 2020.
Results: From the articles included in this review, the studied kinetic variables have the tendency to increase as drop decreases, while the studied kinematic outcomes show a decrease with lower drop. In a similar way, the cadence is usually less as drop increases while the stride length grows.
Conclusions: This research work suggests that shoe drop has an important role on the modification of the human motion's synergistic interactions. After this review, it should be noticed that further works should be carried out attending to only drops and to energetic variables linking the findings of each of them.
Keywords: Footwear; Sport performance; Kinematics; Power; Kinetics.

Efecto del drop del calzado en la biomecánica de carrera y marcha: una revisión sistemática

RESUMEN

Objetivo: el objetivo de esta revisión es examinar el efecto biomecánico del drop del calzado deportivo sobre las variables cinemáticas, cinéticas y espacio-temporales al correr y caminar.
Método: los motores de búsqueda y bases de datos fueron Mendeley, Pubmed, World Wide Science and Science Direct, entre las fechas de enero de 2010 hasta diciembre de 2020.
Resultados: a partir de los artículos que se incluyen en esta revisión, las variables cinéticas estudiadas tienen tendencia a aumentar a medida que disminuye el drop, mientras que los resultados cinemáticos estudiados muestran una disminución con menor drop. De manera similar, la cadencia suele ser menor a medida que aumenta el drop mientras crece la longitud de la zancada.
Conclusiones: este trabajo de investigación sugiere que el drop del calzado deportivo tiene un papel importante en la modificación de las interacciones sinérgicas del movimiento humano. Después de esta revisión, cabe señalar que se deben realizar más trabajos atendiendo únicamente al drop y a las variables energéticas que vinculen los hallazgos de cada una de ellas.
Palabras clave: Calzado; Rendimiento deportivo; Cinemática; Potencia; Cinética.

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Efeito da queda do calçado na biomecânica em corrida e passeio: uma revisão sistemática

RESUMO

Objetivo: O objetivo desta revisão é examinar o efeito biomecânico da queda do calçado sobre as variáveis cinemáticas, cinéticas e espaço-temporais na corrida e caminhada.
Método: Os motores de busca e bases de dados foram Mendeley, Pubmed, World Wide Science e Science Direct, entre as datas de janeiro de 2010 a dezembro de 2020.
Resultados: Através dos artigos que incluem nesta revisão, as variáveis cinéticas estudadas tendem a aumentar à medida que a queda diminui, enquanto os resultados cinemáticos estudados mostram uma diminuição com queda menor. De maneira semelhante, a cadência é geralmente menor à medida que a queda aumenta e o comprimento da passada aumenta.
Conclusões: Este trabalho de pesquisa sugere que a queda do sapato tem um papel importante na modificação das interações sinérgicas do movimento humano. Após essa revisão, deve-se notar que novos trabalhos devem ser realizados atendendo apenas às quedas e às variáveis energéticas que vinculam os achados de cada uma delas.
Palavras-chave: Calçados; Desempenho esportivo; Cinemática; Potência; Cinética.

Introduction

The human being has evolved into a complex system highly specialised in bipedal locomotion and running. Currently, running has arisen as one of the most popular sports worldwide playing a role, which backs up the use of specific footwear. Since the emergence of the ''up-to-now'' running shoe and the running boom in the 1970s, the running footwear industry has broken into a huge market.[1] Thus, nowadays the trainer's industry yields hundreds of different models and designs of sport shoes. The main features that differentiate the first shoe models from the cutting-edge shoes are the overall thickness of the midsole and the ''drop'' or, in other words, the thickness difference between the heel and the forefoot part of the shoe.[2] Besides, the material used and the shoe weight have undergone relevant changes. The application of new technology in the shoe´s manufacturing has brought up the debate related to "biomechanical doping" specifically in the frame of professional running sports. This issue can break into both the commitment of having to change or adapt the rules and requirements to take part in official competitions and the opportunity for the market to get new business, sales and sponsorships due to the fact of making shoes for specific sports and athletes.

Likewise, most running shoes are created to both minimize the injury risk and enhancement the sport performance.[3] Besides, individual responses to footwear modifications can be highly varied. The reasons for this variability are not very well understood at present, making it difficult to suggest the suitable footwear for a given individual.[3] Even so, there is no doubt that different footwear conditions modify running mechanics.[4] The main argument for this is the worn out of human tissues as a cause of expose it at a high level of stress with the result of physical retrogress reply,[3] which will be different according to shoe conditions. However, impact cushioning systems, which almost always increase the heel height of running shoes, also soar ground reaction forces (GRF) lever arms and the corresponding external joint moments at the ankle joint.[5] On the other hand, if we focus on the performance, each kind of footwear has a different effect on the energy consumption (metabolic cost) of a runner[6,7] at the same time that plays a relevant role in the mechanics of the ankle, and to a lesser extent, the knee and hip.[8]

As said before, the drop is one of the main shoe´s features. However, its effects on running mechanic are not clear because of insufficient studies to make strong conclusions. Thus, the aim of this review is to examine the biomechanical effect of the shoe drop on the kinematic, kinetic and spatiotemporal variables in running and walking.

Methods

This review has been carried out through the PRISMA statement for improved reporting of reviews and meta-analyses.[9]

The first step was making an extensive literature search for all articles related to studies that would have measured kinematic and kinetic variables regarding to the use of shoes with different drops. The search engine and databases used were Mendeley, Pubmed, World Wide Science and Science Direct, between the dates of January 2010 to December 2020. Within these libraries, different sets of key words were typed. In Mendeley and Pubmed the word´s chain was *shoe drop kinetic* OR *shoe drop power* OR *shoe drop biomechanics* without applying filters, while in World Wide Science and Science Direct the word combination of *shoe drop kinetic power biomechanics* were used filtering the outcomes by "English" AND "Articles" and "Engineering" AND "Nurse and Health Professions" AND "2010-2020" respectively.

Once the search finished, the next step was to go through the article selection process (Figure 1). Of the total number of articles found, those duplicated were excluded using Mendeley Desktop, version 1.19.4. Finally, the articles were included in the review inasmuch as: 1) they were studies published from 2010 to 2020, both included; 2) they were neither congress abstracts nor systematic reviews; 3) they encompassed the drops of shoes either comparing them directly or checking several kinds of shoe´s design which show different drops; 4) they mainly study kinetic variables and also the kinematic; 5) their investigations are focused on walking or running tasks.

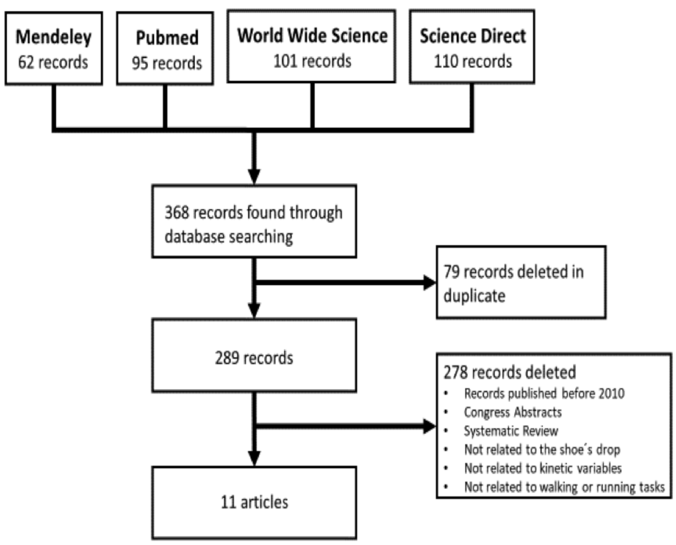

Figure 1. Flowchart of the article selection process.

The next and the last step was to analyse the results achieved by each study. These outcomes have been written in the current review differentiated by the kind of variables, that is, they have been portrayed in reference to kinetic, kinematic and spatiotemporal variables.

Results and Discussion

The total number of articles found among the databases was 368 of which 79 were deleted in duplicate. After making a screening and check the articles regarding to inclusion requirements, 11 of the 289 remaining articles were included in the review. Table 1 depicts the main features of these eleven studies and their main findings.

Gather the current knowledge of kinematic and kinetic variables is the better way to understand the implications of use a shoe with a concrete drop, since according to what[10] said, both joint kinematics and the loading of the structures surrounding the joint need to be addressed using joint moments determined by inverse dynamics.

Attending to kinetic variables, eight research studies analysed the loading rate (BW/s). Except Mo et al.[11] and Giandolini et al.,[12] the other authors found significant differences in loading rates among different drops and as in the case of Goss et al.[13] between rear and fore-foot-strike pattern, showing a greater loading rate in rear-foot striker runners with minimalist shoes. They reported that the lower the drop, the greater the loading rate in healthy runners comparing traditional and minimalist shoes. In his investigation, Giandolini et al.[12] established that their findings related to no significances in loading rate may be due to the

Table 1. Summary of the studies included in the review.

Authors	Shoe Types	Subjects	Protocol	Variables	Outcomes
Besson et al. (2017)	Shoe drop (D0, D6 and D10 mm).	14 female recreational runners (21.4 ± 4.7 years, 164 ± 5 cm, 58.1 ± 6.5 kg).	Overground running at preferred speed.	Stance phase, foot/ground angle, joint angles and moments, GRF.	↑ GRF with Drop-0 than ↑ drop. ↑ Flex. Ankle Moment with ↓ drop. ↓ Flex. Knee Moment with ↓ drop.
Besson et al. (2019)	Shoe drop (D0, D6 and D10 mm).	15 recreational rearfoot female runners (age: 23 ± 6 years, height: 1.63 ± 0.05 m, body mass: 56.7 ± 6.0 kg).	Overground running at preferred speed.	Contact time, loading rate, foot/ground angle, joint angles and moments.	↓ Ankle Dorsiflex. Angle with ↓ drop. ↓ Foot/Ground Angle with ↓ drop.
Chambon et al. (2013)	Shoe drop (D0, D4 and D8 mm) and barefoot.	12 male recreational runners.	Overground running at preferred speed.	Foot/ground angles, joint angles, loading rate, GRF.	↓ Foot/Ground Angle with drop-0 than ↑ drop.
Chambon et al. (2015)	Shoe drop (D0, D4 and D8 mm) and barefoot.	12 male recreational runners (age: 21.8 ± 2.0 years, height: 182 ± 5 cm, body mass: 71.8 ± 5.9 kg, EU shoe size: 43).	Overground running at preferred speed.	Foot/ground angle, joint angles, stance phase duration, loading rate, GRF.	↓ GRF on treadmill than overground. ↑ GRF with ↓ drop. ↓ Foot/Ground Angle at BF and with ↓ drop. ↑ Ankle Dorsiflex. Angle overground for all drops than on treadmill.
Fuller et al. (2016)	Conventional shoe Asics Gel Cumulus-14 (mass=318 g, heel-stack height=32 mm, heel drop=9 mm), and minimalist shoe Asics Piranha SP4 (mass=125, heel-stack height=22 mm, heel drop=5 mm).	26 trained runners (age=30.0 ± 7.9 years, height=1.79 ± 0.06 m, mass=75.3 ± 8.2 kg).	Overground running at 18 km/h (± 1.8).	Stride length, cadence, contact time, joint angles and work.	↑ Ankle work and ↓ Knee work with minimalist shoes (MS). ↓ Planta/Flexor Ankle Angle with MS. ↑ Cadence and ↓ Contact time with MS.
Giandolini et al. (2013)	Standardized shoes: 1) Salomon XT Wings™, mass 400 g, heel height 30 mm, drop 10 mm); 2) Salomon Sense S-Lab™, mass 200 g, heel height 20 mm, drop 4 mm.	22 males and 8 females (18.3 ± 4.5 years, 166 ± 41 cm, 65.5 ± 16.9 kg).	Treadmill running at preferred speed.	Contact time, GRF, loading rate, cadence.	No significant differences in loading rates among different drops.
Goss et al. (2015)	Traditional shoes (>=10-mm drop) and minimalist shoes (drop of 4 mm or less).	37 men, 23 women runners (age=34.9 ± 8.9 years, height=1.74 ± 0.08 m, mass = 70.9 ± 13.4 kg).	Treadmill running at preferred speed.	Loading rate, GRF, cadence, joint angles and work.	↑ Loading rate in rear-foot-strike runners with MS. ↑ Cadence with MS. ↑ Ankle and Knee negative work with traditional shoes (TS) and wearing MS. ↓ Ankle Angle at stance phase with TS than MS.
Lippa et al. (2019)	New Balance® running shoes: 1) minimalist shoe model WR10WW2 and 2) traditional shoe model W880M13.	4 female recreational runners age of 25.0 ± 5.6 years, height of 1.69 ± 0.07 m, and body mass of 60.6 ± 3.4 kg).	Treadmill running at preferred speed.	Loading rate, GRF, joint angles, power and work.	↓ Ankle and Knee power and work with mechanical aged shoe with the two types of shoe.
Mo, Shiwei et al. (2020)	Shoe drop (D0, D4, D8 and D12 mm).	15 recreational male runners.	Treadmill running at preferred speed.	Loading rate, foot/ground angle, stride length, cadence, contact time.	↑ Foot/Ground angle with drop-8 than with drop-4 and drop-0. Different stride length between drop-12 and drop-8.
Richert et al. (2019)	Shoe drop (D4, D8 and D12 mm) and barefoot.	15 male recreational runners (age 24.7 years ± 1.8, height 178.0 ± 5.9 cm, body mass 77.2 ± 6.4 kg, shoe size US 9 ± 1).	Overground running at 4 m/s (± 5%).	Contact time, step length, cadence, loading rate, joint angles and moments.	↓ Ankle moment with heel-to-toe-drop (HTD) 12 and 8 than 4HTD and BF. ↑ Knee moment with 8 and 12HTD than 4HTD and BF. ↑ Ankle angle at initial contact (IC) in all HTD compared to BF. ↓ Knee angle at IC in all HTD compared to BF. ↑ step length and ↓ cadence in all HTD than in BF.
Xu et al. (2017)	Barefoot and neutral running shoes (Brooks©, Radius 06).	28 healthy university students (22 females and 6 males).	Overground walking at preferred speed.	Cadence, stride length, GRF, joint angles, moments and powers.	↓ Knee moment in neutral shoes (NS) than BF at early stance phase. ↓ Knee and Hip moment in BF than NS at pre-swing phase. ↓ Knee and Hip power in BF than NS at pre-swing phase. ↓ Knee flexion and Ankle dorsiflexion angle in NS than BF at early stance phase.

assumption that subjects could have more ease to suit to their new footwear characteristics, as compared to their own running shoes. Besides, in the case of Mo et al.,[11] it may be because the tests were performed on treadmill which has a big influence on the loading rate as showed[14] concluding that the tasks performed on treadmill resulted in lower vertical loading rates for all kinds of drops. On the other hand, just two works of the six[2,13–17] who attended to the peak vertical ground reaction force found remarkable differences. According to Besson et al.,[16] vertical ground reaction force exhibits higher values right after the transient peak of the stance phase in drop-0 (D0) condition compared to drop-6 (D6) and drop-10 (D10), while Chambon et al.[18] noted significant differences among drops (the highest vertical ground reaction force in D0) on the treadmill but not overground. As Chambon et al.[18] reported, it is likely that treadmill stiffness was lower than ground stiffness and, in the Benson´s investigation, the differences can be related to the fact that the subjects ran at their preferred speed.

Talking about the joint moments (Nm/kg), Richert et al.[19] had found that the maximum ankle moment was significantly smaller in the two highest heel-to-toe-drop (HTD) conditions (12HTD and 8HTD) than 4HTD and barefoot (BF); and 4HTD was not significantly different from BF. The minimum ankle moment was not significantly different between the four conditions. For the knee joint moments, 12HTD and 8HTD showed a significantly greater maximum than 4HTD and BF and 4HTD was greater than BF. However, data of the hip joint were not significantly different between the four conditions. Similarly, Besson et al.[20] reported that there was a main effect of shoe drop on knee external moment, but post-hoc analyses did not show any difference between conditions, however, a lower knee external moment was observed for D0 compared to D6 and D10 during the push-off phase. The Statistical Parametric Mapping analysis showed significantly higher net ankle external flexion moments during the braking phase for D0 compared to D6 and D10, while there was no main shoe drop effect on the net hip moment. Xu et al.[15] asserted that compared to walking barefoot, walking in neutral shoes significantly reduced the moment in the sagittal motion plane at the knee joint, and no significant difference was discovered in other joint moments in the early stance phase at the hip, knee, or ankle joints. On the other hand, from the pre-swing phase to the initial swing phase of the gait cycle, the difference in the value of joint moments reappeared. Moment at the hip joint was decreased markedly by walking barefoot compared to walking in neutral shoes. Similarly, moment at the knee joint was reduced significantly when walking barefoot. In the case of Besson et al.,[21] D0 showed an increased net joint ankle flexion moment during the braking phase and a reduced net knee flexion moment in the push-off phase compared to D6 and D10 conditions. As it can be seen, these four authors found disparate results regarding to joint moments. This may not be due to the design of each study because they are very similar since the subjects are recreational runners, perform the trials at their preferred speed overground. So, these outcomes can come from the ability of each subject to adapt to the new shoe conditions which would show that the running pattern linked to each runner play an important role on the adaptive response of the musculoskeletal system to external perturbations.

The last kinetic variables analysed belong to energetic variables, as they are the power (W/kg) and the mechanical work (mJ/kg). Lippa et al.[2] commented that there was shoe–aging (and in consequence on the drop modification) interaction effects for knee power and work. Both power and work decreased with mechanical aged shoe both on the ankle and knee with the two types of shoe. Xu et al.[15] reported, just in the last stance phase, that hip power of walking barefoot was significantly lower than those of walking in neutral shoes. Additionally, the knee power of walking barefoot was markedly lower than that of walking in neutral shoes. For their part, Fuller et al.[22] established that running in minimalist shoes increased negative and positive work at the ankle joint and decreased negative and positive work at the knee joint, while Goss et al.[23] affirmed that the traditional-shoe rear-foot (TSR) runners demonstrated greater ankle-dorsiflexion negative work than minimalist-shoe anterior-foot (MSA) and minimalist-shoe rear-foot MSR runners. The TSR runners also demonstrated greater knee-extension negative work than MSA and MSR runners. The MSA and MSR runners demonstrated greater ankle–plantar-flexion negative work than TSR runners. After what was said, regarding to energetic variables, it can be concluded that the mechanical power and work decrease with low drops and vice versa. This fact could be related to joint configuration that drops compel subjects to get even though these modifications can seem small, currently have a huge implication on the force and on the direction of the force that muscles can develop.

Moving on to the kinematic variables, the authors mainly focus their attention on the footstrike angles and the joint angles. According to Mo et al.,[24] significant effects were demonstrated on footstrike angle with a greater footstrike angle during running in drop-8 (D8) compared with drop-4 (D4) and D0. In the same way, Besson et al.[20,21] found that the foot/ground angle at contact exhibited lower values in D0 compared to D6 and D10. In the same line of results, Chambon et al.[14] reported that foot/ground angle showed lower values at touchdown during barefoot running compared to shod running, while D0 condition also induced significant lower foot/ground angle at touchdown than D8 condition both overground and on treadmill. Chambon et al.[17] supported the other authors finding also that foot/ground angle at contact was lower in D0 condition than in D8. Studies all get the same results, the lower drop, the smaller foot/ground angle what are logical findings since drop adjusts the foot´s tilt with respect to the flat plane. Notice that the effect of drops on the foot/ground angle at contact is a key variable as has an important influence on other variables. For example, previous studies have reported an increase in loading rate when decreasing the foot/ground angle.[25–27] However, these findings do not imply that the foot/ground angle is the only determinant of the transient impact peak. Malisoux et al.[28] speculated that runners possibly adapted the inclination of their trunk to compensate for the shoe drop.

On the other hand, Richert et al.[19] found that for the ankle, all HTD conditions showed a significantly higher angle at initial contact (IC) and lower minimum angle compared to BF. However, there were no differences between the HTD conditions. Apart from a minimum knee angle, all knee kinematic variables showed significant differences between HTD conditions and BF. The maximum knee angle was greater for the HTD conditions, whereas the angle at IC was lower. The minimum knee angle showed significant differences between BF and both 4HTD and 8HTD. For hip joint kinematics, there were no statistically significant differences across the HTD conditions or in comparison with BF. Besson et al.,[20] concerning joint angles at contact, reported no effect of shoe for knee or hip angles, but significantly lower ankle dorsiflexion angle for D0 compared to D6 and D10 between, while ankle dorsiflexion angle showed lower values at touchdown during D0 condition compared to D6 and D10. However, concerning knee and hip joints angles there was no significant difference between the three conditions, neither at touchdown, nor during the stance phase.[21] Xu et al.[15] found that walking in neutral shoes attenuated the flexion angle of the knee at the early stance phase, and the dorsiflexion angle at the ankle joint, when compared with walking barefoot. Additionally, no significant difference was demonstrated in flexion and extension angles of the lower limb joints between the two conditions at the late stance phase. Fuller et al.[29] got the results of what runners landed with a more plantar-flexed ankle at initial contact in minimalist shoes, but no different were found in peak ankle dorsiflexion or ankle angle at toe-off between shoes. According to Goss et al.,[23] the TSR group demonstrated less ankle excursion during stance phase than the MSA group. The most obvious difference occurred at initial contact, with the TSR group contacting the ground with the ankle in more dorsiflexion than the other groups. Ankle excursion for the MSR group did not differ from the other 2 groups. The TSR group demonstrated greater total knee excursion during stance phase than the MSA group did and the major difference in angle occurred during midstance. Finally, Chambon et al.[14] showed a significant task/footwear interaction concerning ankle joint angle and knee joint angle at touchdown. While barefoot condition did not show any difference between overground and treadmill running in ankle and knee joint angles at touchdown, every shod condition showed significant modifications of these three variables. Ankle angle at touchdown exhibited higher dorsiflexion angle during overground running than during treadmill running for D0, D4, and D8 conditions. Knee angle at touchdown showed lower angle during overground than during treadmill task for shod conditions. As shown, the joint angles outcomes rely heavily on the shoe conditions, task speed and ground stiffness. Besides, shoe drops have a higher influence on the variability of the knee and ankle angles at the beginning of the stance phase what may prove that these two joints have a relevant role according to get stability and control the kinematic chain.

To conclude, in regard to spatiotemporal variables, Mo et al.[11] reported that HTD exhibited a significant effect on stride length. Post-hoc pairwise comparisons showed that stride length was significantly different between drop-12 (D12) and D8. Cadence showed a significant main effect with non-significant pairwise comparisons while no significant effects were demonstrated on contact time. By his part, according to Richert, et al.,[19] all HTD conditions showed a significantly higher step length and lower cadence than BF. Contact time showed a significant main effect with non-significant multiple pairwise comparisons. Similarly, Fuller et al.[29] found that running in minimalist shoes increased the stride rate but decreased the contact time. Goss et al.[23] declared that step frequency differed among groups (minimalist and traditional shoe groups) (higher step frequency in minimalist). On the other hand, Xu et al.[15] showed that statistics analysis of spatial-temporal variables suggested that there were no significant differences in cadence or stride length between the two conditions (walking in neutral shoes and in barefoot). Finally, the utterance that the fact that the stance phase duration was similar in all conditions is supported by Besson et al.[21,30] and Chambon et al.[14] with the outcomes that there was no effect of shoe drop on contact time. Taking into account these results, the shoe conditions have almost no effect on contact time, while the stride length rises with minimalist shoes and the drops have a noticeable repercussion on it mainly in the highest drops, the opposite of what happens on cadence, which has a higher variability in the lowest drops. The study's findings are in the same line of results except in the case of Xu et al.[15] who did not report significant effects neither on stride length nor on cadence what could be because it is the only research work with walking protocol.

Conclusion

Casting the sight back, over the past two decades the research works related to footwear features have focussed their effort on understanding of how the shoe design affects to biomechanical variables regarding to lower limbs. The shoe drop has proved to have a relevant repercussion on all kind of biomechanical variables, but these effects can be altered if the footwear has other significant changes like which occur between minimalist or traditional shoes, or even in the case that the same shoes have their sole yield with different materials as the way of deform and aged are distinctive. Besides, attending to the variables that have repercussions on the musculoskeletal system, the authors have investigated them through a discrete method or, in other words, without linking their outcomes among these variables. Thus, future research should focus on how these variables influence each other taking into account only the drop like shoe variable and, on the other hand, they should study more in detail the energetic variables on drop shoes since they include the most relevant information about human movement.

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