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THE INFLUENCE OF SURFACE TYPES ON FOOT KINEMATICS DURING RUNNING AND WALKING: A SYSTEMATIC REVIEW

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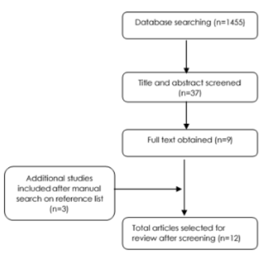
Graphical abstract



Flowchart of reviewed study

Abstract

Variations in running or walking surfaces may contribute to injury, due to the modification of lower extremity motion depending on surface conditions. Limited sources clearly identify that injuries can be caused by altering foot kinematics on numerous surface types. The purpose of this review paper is to identify the relationship between type of surface and foot kinematics whilst running or walking. The search strategy was completed via the Science Direct database and manual searching using a reference list of the reviewed articles. The quality of the reviewed articles was identified via methodological quality assessment. Twelve full-text articles were involved in the quality assessment out of a total of 1455 citations yielded at the beginning of the electronic search. Most of the reviewed papers classified as "high quality" did so by providing sufficient information on research objectives, study design, equipment design, study interest, main outcomes as well as key findings. The majority of the reviewed articles espoused that foot kinematics changing in relation to running or walking surface type and the category of participant. The application of dynamic modelling and finite element analysis was recommended to identify the injury in detail. Thus, further research is suggested to enhance knowledge of injuries caused by running or walking on different surfaces.

Keywords: Running, walking, ground surface, kinematics, and review

Abstrak

Kepelbagaian permukaan semasa berlari dan berjalan boleh menyebabkan kecederaan kerana pengubahsuaian pergerakan bawah badan bergantung kepada keadaan permukaan. Sumber –sumber yang mengenalpasti punca kecedaraan yang disebabkan oleh perubahan kinematik kaki di atas pelbagai permukaan adalah terhad. Tujuan kertas kajain ini adalah untuk mengenalpasti hubungan di antara jenis permukaan dan kinematic kaki semasa berjalan dan berlari. Strategi pencarian dijalankan menggunakan pangkalan data 'Science Direct' dan pencarian manual menggunakan senarai rujukan artikel-artikel yang diulas turut dilaksanakan. Kualiti artikel-artikel yang dirujuk dikenalpasti melalui penilaian kualiti metodologi yang melibatkan 12 artikel teks penuh daripada 1455 petikan artikel yang diperoleh melalui carian elektronik . Kebanyakan artikel-artikel yang diulas diklasifikasikan sebagai berkualiti tinggi dengan penyediaan maklumat mengenai objektif kajian, rekabentuk kajian, rekabentuk peralatan, fokus kajian, dapatan utama dan penemuan penting. Majoriti artikel yang diulas mendedahkan bahawa kinematik kaki berubah bergantung kepada jenis permukaan untuk berlari atau berjalan dan kategori individu yang berjalan dan berlari tersebut juga menyebabkan kecederaan semasa aktiviti tersebut. Penggunaan pemodelan dinamik dan analisis unsur terhingga telah dicadangkan untuk mengenalpasti kecederaan yang mungkin terjadi secara terperinci. Oleh itu, kajian lanjutan dicadangkan untuk meningkatkan pengetahuan mengenai kecederaan yang disebabkan oleh berlari atau berjalan diatas permukann yang berbeza.

Kata kunci: berlari, berjalan, permukaan bumi, kinematic dan ulasan

1.0 INTRODUCTION

In daily activities, people walk or run over a variety of surfaces with different characteristics such as irregular or inclined surfaces and slippery floors with a variety of surface stiffness or hardness. This includes surfaces like grass, turf, vinyl, asphalt, concrete and rubber. Surface variation may cause falls or even injury because the modification of lower extremity motion is dependent on surface conditions. For example, subjects are exposed to a greater falling risk when walking on rocky surfaces due to variability of kinematics measures and temporal spatial parameters affected by surface type [1]. Moreover, subjects alter their walking style to a conservative pattern when walking on irregular surfaces to maintain stability [2] and prevent injury. Each surface resulted in different effects on lower extremity kinematics where small changes may cause injury [3].

Gait kinematics during running have been speculated to be a contributing factor to lower extremity injuries causing patellofemoral pain and iliotibial band syndrome due to increased non-sagittal motion of the pelvis and hip [4]. Individuals consistently have to adapt their kinematics strategy to effectively negotiate the running or walking surfaces. For instance, an individuals increased minimum toe clearance (MTC) on uneven surface (eg. rock surface) reduce their risk of tripping and lowers their shoe-floor angle at heel strike to decrease their risk of slipping [1]. Human also adapted to 'potentially' slippery surfaces that led to significant differences in gait kinematics during walking. These adaptations resulted in significant reductions in joint moments. It was noted that the moment generated at the lower extremity joints in knee and hip appear to be used more than the ankle to control slip potential [5]. Surface hardness also influences the kinematics response of human gait. The increased of surface hardness requires human to increase the impact force in order to facilitate timing discrepancies between subtalar and knee joint function, that resulting in a transition of the pronation curve from a unimodal to bimodal configuration [6]. On the other hand, although the stiffness of the treadmill and overground is different, the kinematics of treadmill and overground gait was found qualitatively and quantitatively very similar [7]. Overground is a common term used for surfaces on or above the ground such as grass and concrete.

It is generally known humans altered their leg kinematics during movement over surfaces with various mechanical properties [8]–[10]. However, it is unclear if these biomechanical adaptations are related to the perceived injury risk associated with surface mechanical properties [11]. Surface characteristics and related biomechanical alterations may be an important factor related to injury frequency and severity [12]. Therefore, this systematic review outlined the published articles that related to running and walking movement on different surfaces in order to identify the relationship between surface characteristics and foot kinematics response. Quality analysis on the available literature was carried out to summarize the experimental protocol used to quantify the effect of running or walking surface on foot kinematics.

2.0 METHODOLOGY

2.1 Search Strategy

Science Direct database was used to complete the electronic literature search in June 2015. Search terms used included 'foot', 'kinematics, 'walking' and 'running'. The search on a combination of compatible keywords to surface such as 'artificial grasses, 'turf', 'concrete' and 'rubber mat' has also been done to perform an inclusive search. Search on Science direct database was performed for articles published from 1997 to 2015. Additional manual search on a reference list of reviewed articles has also been done to ensure no overlooked articles.

2.2 Eligibility

English full-text articles only were selected from the electronic database. The search strategy was individually performed by an author. Screening process of titles and abstract was involving articles that evaluated walking or running on different surfaces. Articles that fulfilled the following criteria were considered: (1) study included human participant, (2) focus on walking or running, (3) studies on foot kinematics on different surfaces and (4) studies which involving experimental work using motion capture system analysis and marker placement. Subjects' participation was not limited to age, gender or category of participants for example, athlete, recreational runner or patient on rehabilitation.

2.3 Review Process

The title and abstract were firstly screened based on eligibility criteria. A full-text evaluation was accomplished if the title and abstract could not provide sufficient information of the article on screening process. The selected articles were reviewed and assessed by two reviewer (N.AA and K.S.B.). Removed articles were re-screened to avoid any overlooked information.

2.4 Assessment of Methodological Quality

There was no validated and standardized methodological assessment tool exist in the area of studies in foot kinematics during running on different surfaces. In addition to data extraction, a systematic methodological assessment is performed to improve the standard review and lessen reviewer's bias. Peter *et al*. [13] customized 19 questions as quality assessment tool to evaluate 20 reviewed articles. The customized question is related to the research aims that includes objective, design of the study, findings, limitation and conclusion.

The assessment of present review was based on the adjustment of previous appraisal question [13], [14]. The selected articles were evaluated by reviewers with the modified appraisal questions that related to foot kinematics in running on different surface (Table 1). Previous articles were assessed according to questions in Table 1, and marked based on the information obtained. Each question will be evaluated with score 2, 1 or 0 for detailed information, limited information and no information, respectively. Score percentage of the information gains indicating the quality of the selected articles. Higher percentage indicates more detailed information provided.

Table 1 Methodological quality assessment used in this review

Question
1. Were the study objectives clearly stated?
2. Was the study design clearly described?
3. Were the subjects' characteristics and details clearly provided?
4. Was the practice trial in the study clearly stated?
5. Was equipment design and set up clearly described?
6. Were run or walk gait movement clearly described?
7. Was the study involving different running/walking surfaces?
8. Was the foot model used clearly described?
9. Were the appropriate statistical methods used in data analysis clearly defined?
10. Were marker placements accurately and clearly described?
11. Did the results support the key findings?
12. Were the main outcome measures clearly stated?
13. Were the limitations of the study clearly mentioned?
14. Were the conclusions drawn from the study clearly summarized?

3.0 RESULTS AND DISCUSSION

Result of the review process in this study was shown in Figure 1, where 'n' represent the number of papers. The search strategy was performed by N.A.A and K.S.B. 1455 citation yielded at the beginning of electronic search based on keywords used. Search on Science direct databases was performed for articles published from 1997 to 2015. Then, screening process for title and abstract retrieved 37 articles that related to the main focus of the review. Only nine articles were selected for detailed review. Article that not satisfy the eligibility criteria as mentioned in section 2.2 were removed. Three articles were chosen from reference list, totals up 12 articles for the final review process._This review outlined and summarized the published articles that related to running and walking movement on different surfaces from the year of 1997 to 2015. The relationship of surface and foot kinematic during running or walking movement is essential to be understood in order to alter a correct and efficient running or walking movement on different surfaces in order to prevent injury.

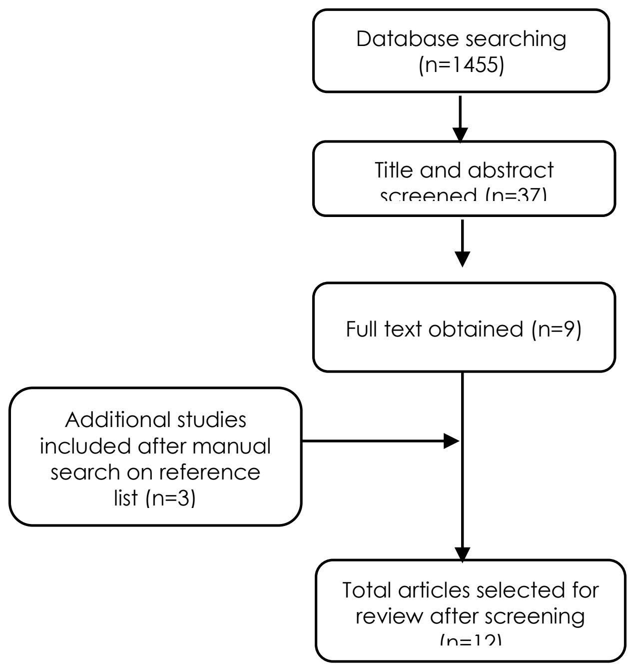


Figure 1 Flowchart of reviewed study

Main findings of previous articles highlighted that kinematic parameters, particularly in the lower extremity were affected by a variety of surface characteristic and types, as summarised in Table 2. The score obtained for methodological quality assessment is presented in Table 3. Most of the reviewed papers were classified as high quality by providing sufficient information on research objective, study design, equipment design, study interest, main outcome as well as key findings. Only four [1], [15]–[17] reviewed articles were clearly mentioned about the limitations of the study. Many of them did not provide information on practice trials. There were only three reviewed articles [3], [6], [18] completing at least 79% to 89% of the questions. The rest of articles completing 69% to 79% as the overall percentage of the quality assessment score that was ranged from 69% to 89%.

The reviewed articles were involving participants with various physical characteristics as listed in Table 4. Most of the articles clearly stated the physical characteristics of participant. Only three reviewed articles did not mentioned about the mean of height and weight of subjects involved [7], [15], [16]. The number of participants selected was inconsistent among the reviewed articles. Based on the review, the highest number of participants selected was 35 and the lowest was five. In addition, the purpose of the research will vary gender [1], [4], [5], [15], [16], [18]–[20] and age group [16], [17] of the participants. Age group can be classified as young adult and older adult [16], [17] that are able to perform running or walking gait movement without any problems. Only a few articles focus on specific category of participants such as athlete [3], experienced runner [4], recreational runner [6] or normal healthy subjects [1], [5], [7], [15], [17], [18]. Methodological quality assessment was applied to the selected retrieved articles to assure the quality of the articles [14] and minimizes reviewers' bias [13]. As mentioned in section 2.4, the articles were assessed based on information obtained from the answered questions. The score obtained indicates the quality of the articles. Meta-analysis was not employed due to insufficient similarity studies for the same running or walking movement as stated in reviewed articles. A uniform measures were unable to be identified. Percentage of the score shown in Table 3 indicating the rating quality for each article. High percentage representing a high quality of paper as there is more information provided.

Each of the articles has specific surface criteria to be investigated. The surface criteria can be divided into type, condition and properties. As summarized in Table 4, the type of surface studied can be classified into three category of application; indoor leisure walking [4]–[6], [15]–[17], [19], outdoor leisure walking/running [1], [18] and outdoor sport [3]. However, none of the previous studies investigated indoor sport surface

All articles used a specific experimental protocol for either running or walking on different surfaces as listed in Table 4. Nine articles [1], [4], [5], [7], [15], [16], [18], [19], [21] performed experiment on walking whereas three articles [3], [6], [22] investigated kinematics response during running. The experiments were conducted for distance between 5 m [1], [18] to 17 m [23].

An extensive study had been made to decrease the injury rate for long distance runner by investigating the number of injury occur in a designed program [24]. This study reported that, running surface were affecting the number of injuries. On the other hand, the main finding obtained from the reviewed articles was foot kinematics during running or walking movement changes correlate with surface types. The reviewed articles unanimously agreed that surface type altered the foot kinematics during running or walking gait either in movement or temporal spatial. Gates *et al.* [1] stated that the variability of all step parameters and kinematics measures was influenced by the surface types. The statement is in agreement with other studies of walking on compliant or irregular surface [18]. Basically, foot kinematics parameter measured by reviewed articles showed a significant different on each surface such as heel angle [19], dorsiflexion [1], [3], inversion [3], ankle angle [22], cadence [15], internal rotation, adduction [4], step width and step time [17]. These findings consistent with the hypothesis that surface condition causative to injury that associated with foot alteration in adapting surface condition. Moreover, participant category also affected the foot kinematics. Age, gender and category of participants resulted in unique foot kinematics during running or walking on different surface type.

Optical tracking equipment that analysing gait in term of dynamic modelling was shown as an effective method for measuring three-dimensional kinematics and kinetics of the human body [25]. Dynamic modelling could define segments of the body part, where it can be analysed as single rigid body or multi-segment. Foot kinematic measurement of previous studied did not involve multi-segment analysis. Multi-segment analysis could provide an accurate measurement by investigating the relation of each segment in a foot during motion. Multi-segment analysis is required to overcome single rigid segment or vector assumption of foot using standard gait analysis and consider deformity in dynamic modeling of foot as well [26]. Accurate foot kinematics measurement was substantially to identify alteration in foot kinematic in relation to surfaces type and causative to injury.

Limited studies in this review revealed the relationship of surface type with injury since inadequate related information was explored. Studies of surface on a specific application such as indoor sport surface were not conducted. Ground surface was considered as an important tool in any sport activity in playing perspective. Selecting ideal sport surface was crucial in an endeavor to achieve excellent sport performance. Hamid et al. [27] found a significant association between time-loss injury (defined as an injury that implicated the next scheduled session of a player or an athlete) with match surface in futsal. They revealed that 68% of time-loss injuries often occurred if the matches played on vinyl surface. Vinyl is one of material used in polymeric and sheet flooring category that commonly prepared in sheet form with a foam backing. Foam backing enables a 'point elastic' or 'mixed elastic' floor which is a major contributor in preventing injury. 'Elastic area' or 'combined elastic' allow high levels of force reduction without excessive deformation and lack energy restitution problem as well as better shock absorption during heel strike of gait. Without foam backing, sheet materials was used to provide top wearing surface with a 'combine elastic' system but ultimately rely on quality of undercarriage on the sheet was laid. Precautions must be taken to prevent irregularities in the underlying surface that may induce injury. Gates *et al.* [1] finding was in agreement with the notion that surface type associated with injury, reported that participant exposed to a higher risk to injury when walking on an irregular surface. Contact with a floor surface enables several of physical injury to occur, such as bruising, friction, burns or bone fracture due to severe body impact.

On the other hand, joint twisting from restricted foot movement also can cause strain from repeated foot impact and muscle fatigue or inflammation. Inflammation of a plantar fascia ligament could lead to plantar fasciitis (PF). PF is one of major injuries that lead to heel pain which not yet comprehensively understood. Among various caused factor, biomechanical factor is assumed as the main reason that developed PF. Although the magnitudes of pronation and loading remains difficult to define quantitatively, the excessive kinematics and kinetics are believed to act as a key role in the development and prolongation of recalcitrant PF [28]. Hence, finite element analysis (FEA) can be considered as an effective method to study of PF because the plantar fascia can be developed in foot model realistically. FEA is able to collect information about internal stresses/strain of plantar fascia during stretch non-invasively [29].

Obviously, experiment on running requires the longer distance compare to test on walking. Three [5] to twenty [6] repetition trials in recording the kinematic data were carried out. However, most of the articles performed the experiment for 5 trials [1], [7], [16], [19] but six articles did not clearly mentioned the number of trials used [3], [4], [15]–[17], [22].

Kinematic data can be obtained via application of dynamic modelling. However, none of reviewed articles used the segmented model for modelling in measuring the kinematics data. Single rigid model was considered had been applied in most of the aforementioned reviewed articles to perform kinematics measurement for lower limb specifically, where can be classified into movement and temporal spatial. Kinematics of parameters in movement category [1], [3]–[5], [7], [15], [19], [22] can be classified into plantar flexion/dorsiflexion, extension/flexion, and adduction/abduction. While parameter measured as temporal spatial [6], [16]–[18] is including step length, speed, angular velocity, horizontal/vertical heel velocity, walking velocity, double support time, cadence, step width, toe clearance and angle

Kinematic data was obtained using combination of force plate, reflective markers and camera system by most of the articles [4]–[7], [15], [19], [22]. Beside from this combination, the kinematic data was also measured using other systems such as infrared emitting diode surface EMG with Optotrak cameras [18], force sensing resistor with Optoelectronic cameras [21], tracking LEDs [5] and scanner units [16].

One article mentioned about using 3D motion capture analysis system in their experiment without detailing the list of equipment in the system [3]

There were some limitations of this systematic review. This review only included English-based published articles. The search engine also involved only one database. Therefore, several articles possibly have been neglected. In addition, the involvement criteria of the selected articles limited to kinematic findings only. Therefore, kinetics related findings of articles was excluded.

4.0 CONCLUSION

This review found that the foot kinematics is influenced by ground surface for running or walking movement. It may lead to injury for certain extent. Foot kinematics was altered depending on surface condition. However, detail information on causes of injury due to surface properties was still insufficient. The application of dynamic modelling and finite element analysis is probably needed to identify the injury in detail. Thus, further research is required to enhance knowledge of injury caused by running or walking on a different surface.

Acknowledgement

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Table 2 Data extraction from reviewed articles

No.	Protocol	Foot model	Equipment	Independent variable	Dependent variable	Findings
1	Subjects walked as fast as possible along 5 walkaways of 6.08m x 0.81m for each floor type in 3 surface conditions from dry to wet followed by glycerol wearing leather loafers as standard footwear with heel material replaced by flat Neolite for 5 trials.	Not mention	Motion tracking system (200 Hz) Force plate (1000 Hz) 17 passive reflective markers	Floor type: • Quarry tile with metro tread • Quarry tile • Vinyl with wood finish • Marble tile • Glazed porcelain tile with silver finish Surface condition; dry, wet & glycerol	Gait kinematic parameters; Step length • Walking speed at heel strike • Heel angle with floor • Heel angular velocity • Horizontal heel velocity • Vertical heel velocity • Ankle angle Perceived slipperiness rating (PSR) Available coefficient of friction (ACOF) Utilized coefficient of friction (UCOF)	Kinematics variables especially heel angle became main predictor of PSR in glycerol condition UCOF & ACOF main predictor of PSR under wet & glycerol condition. Significant of difference is major predictor of PSR under wet condition.
2	Subject performed an unanticipated cutting maneuver at an angle 30°& 60° on a natural surface pitch (NT) & artificial turf. Start with 8 m acceleration phase at speed 4-5m/s before cutting with change of direction followed by 5 m acceleration phase.	Not mention	3D motion capture analysis system 30 active markers Scanner Infrared timing velocity gates	Running & cutting surface; Natural grass (NT) & artificial turf (AT)	Parameters of sagittal, frontal & transversal ankle and knee angle at foot strike (FS) and weight acceptance (WA).	<u>Ankle</u> No significant effect for main surface effect for FS & WA Large effect size at FS for dorsiflexion & inversion angle (AT>NT) Large effect size at WA for inversion angle (AT>NT) & external rotational angle (AT<NT) Interaction effect of surface & cutting angle show significance level with high effect size at FS & medium at WA. <u>Knee</u> Significant effect of surface type comparison showed by internal knee rotation angle at FS. Interaction effect of surface & cutting angle show medium & large insignificant effect size for knee valgus.
3	Subjects walked over a 5 m level ground walkway and 4.2 m long rock surface walkway at 4 controlled	Not mention	20 camera infrared (120 Hz) 55 reflective markers	Walking surface; Rock surface (RS) & level ground (LG)	Joints kinematics; • Foot angles • Ankle plantar flexion/dorsiflexion	Surface types affect variability of all step & kinematics parameters. Significant kinematics differences

No.	Protocol	Foot model	Equipment	Independent variable	Dependent variable	Findings
	speed that normalized according to Froude Number; 0.06, 0.1, 0.16 & 0.23 for 5 trials (5 left & 5 right strides)				• Hip flexion • Knee flexion	between walking surfaces during swing phase. Increased of hip and knee flexion as well as ankle dorsiflexion at RS
4	After ran on unperturbed runway, subject ran at a constant self-selected speed along a 17 m wooden perturbed runway with 2 consecutive force plates in the middle until a successful trial achieved (participant centered both touchdown on plate). The second plate was set on 4 different elevation; 0, 5, 10 & 15 cm.	Not mention	2 force plate (2000 Hz) Reflective joint markers 12 cameras (240 Hz) Disposable surface electrode	Types of track; • Unperturbed running • Perturbed running without step • Perturbed running with step of 5 cm • Perturbed running with step of 10 cm • Perturbed running with step of 15 cm	Joint stiffness EMG Kinematic of lower limb; ankle & knee angle Dynamic of lower limb; GRF	Kinematic of lower limb correlated with pre activation of gastrocnemius medialis (GM) while running over step of different height. For each run, kinematic parameter highly significant correlated to pre-activation of GM Relation of kinematic parameter with tibialis anterior (TA) is lower than GM.
5	Subject walked on 15 m laboratory walkway at self-selected speed for at least 3 complete cycles followed by treadmill walking for 2 minutes on side-by-side treadmill force plate.	Not mention	Force plates (308 Hz) 10 camera motion analysis system (250 Hz) 16 retro reflective markers	Walking surface; Over ground & treadmill	Kinematic parameters of hip, knee and ankle • Extension/flexion • Adduction/abduction • Plantar flexion/dorsiflexion Kinetics parameter Temporospatial parameters	Most of kinematic maximum & minimum values are significantly different between the surfaces. Kinematic and kinetic of gait have similar patterns.
6	Subject performed 5 walking trials along a 7 m long walkway of 3 different surfaces in random order at self-selected pace wearing 8 different shoe conditions.	Not mention	2 scanner units (200 Hz) 2 active marker	Subjects age group; Young adults & older adults Surface condition; • Control (dry linoleum floor) • Irregular (2 layers of 20 mm thick soft foam over small blocks of wood with uneven shape & size covered with artificial grass) • Wet (linoleum floor spread with water) Footwear features; • Standard	Temporo-spatial gait variables • Walking velocity • Step length • Double support time • Cadence • Step width • Toe clearance • Horizontal velocity of heel marker at heel strike • Absolute sagittal shoe-floor angle	Irregular vs control surface Decreased walking velocity, cadence, step length, double-support time, heel horizontal velocity Increase step width, toe clearance Wet vs control surface Decrease walking velocities, step length, shoe-floor angle at heel strike Increase step width Significant surface x group interaction for toe clearance & step width Significant surface x shoe interactions between standard & soft sole shoes for step length &

No.	Protocol	Foot model	Equipment	Independent variable	Dependent variable	Findings
				• Elevated heel • Soft sole • Hard sole • Flared sole • Beveled heel • High-collar sole • Tread sole		shoe-floor angle at heel strike
7	Subjects walked at 1.2, 1.5 & 1.8 m/s and ran at 1.8, 2.7, & 3.6 m/s with surface inclination 0%, 10% & 15% grade. Speed-incline combinations order is randomized approximately 10 s of data for each subjects. (treadmill)	Not mention	40 reflective marker 8 cameras passive marker system (200Hz)EMG	Gender Running & walking speed Inclination	Joint kinematics: -lateral pelvic tilt -hip internal rotation -hip adduction EMG	<u>Running</u> Peak hip internal rotation: Female > Male; [P<00.4) Peak hip adduction: Female > Male; [P<0.001] Hip adduction excursion: Female > Male; [P<0.02] Peak hip flexion: Female = Male <u>Walking</u> Lateral pelvic tilt excursion Female > Male; [P<0.001] Peak hip flexion:Female = Male Female displayed greater non-sagittal motion.
8	Subject walked on 15 m walkway at comfortable self-selected speed for 5 trials with at least one clean strike. Then, walked on treadmill with the same speed set for 3 x 30 s trials.	Not mention	10 camera Force plate (120 Hz) AMTI compound instrumented treadmill	Running surface; Treadmill & over ground	Kinematic parameter • Hip flexion • Hip extension • Hip abduction • Hip adduction • Hip ext rotation • Hip int rotation • Knee flexion • Knee extension • Ankle plantarflexion • Ankle dorsiflexion • Pelvic tilt anterior • Pelvic tilt posterior • Pelvic obliquity max • Pelvic obliquity min • Pelvic rotation max • Pelvic rotation min • Spine flexion • Spine extension • Spine lateral flexion max • Spine lateral flexion min • Spine rotation max	Kinematics of treadmill & over ground gait were similar 12 of 22 kinematics parameter maxima – statistically significantly different but magnitude of difference, less than 2°. Kinematics & kinetics differences are within the range of repeatability of measured kinematic parameters.

No.	Protocol	Foot model	Equipment	Independent variable	Dependent variable	Findings
					• Spine rotation min Kinetic parameter	
9	Subjects walked on baseline ground (thin length of green mat placed on the ground) at self- selected speed initiating with left foot and followed by compliance surface (medium density foam; 5 m x 0.91 m x 0.12 m with stiffness 13.13 kN/m) for 10 trials each.	Not mention	3 Optotrak cameras 23 infrared emitting diodes surface electro-myography	Walking surface condition; Baseline over ground Compliance surface (foam)	Toe trajectories Step width Step length Step time Step velocity Centre of mass (CoM) Muscle activity	Initial maximum and minimum peak toe trajectories tended to increase during the compliant surface condition Step widths, lengths, and times tended to increase while walking on the compliant surface. (significantly larger than over ground steps) No trial effects were seen in step width, length, or time.
10	Subject walked on 10 m long x 1.5 wide walkway under four different surface conditions in randomized order at a comfortable speed. * Flat surface - vinyl-tiled floor *Irregular surface - triangular wooden prism distributed underneath a layer of industrial carpet	Not mention	2 force-sensing resistor 3 infrared-emitting diode marker Optoelectronic camera system (100 Hz)	Participant age: Young women & older women Surface condition; • Flat surface with regular lighting • Flat surface with lowlighting • Irregular surface with regular lighting • Irregular surface with low lighting.	Step width, step time, gait speed	Surface type significantly affected step width variability and step time. Light level showed no significant effect on any of the gait parameters. Step width variability was significantly greater in older women than young women
11	Subject walked at comfortable pace and naturally as possible at 27 conditions(3 ramp angles x 3 floors x 3 trial types) randomly 3 types of trials Baseline (subjects certain floor is dry) - subject walked to the top of the ramp, turned around & walked down the ramp. Anticipation – subjects	Not mention	Force plate (350 Hz) Tracking LEDs	Ramp angles (0, 5 & 10°) Floor type; • Vinyl tile • Smooth painted plywood • Rough, silicate impregnated painted plywood	Kinetic parameter Kinematics parameter • Stance duration • Heel velocity in the direction of motion • Peak rearward heel velocity in the direction of motion • Peak forward heel velocity in the direction of motion • Heel acceleration • Peak heel acceleration • Foot angular velocity • Foot-ramp angle • Shank-ramp angle	Significant gait changes are made when there is potential risk of slipping even subjects were asked to walk as natural as possible.

No.	Protocol	Foot model	Equipment	Independent variable	Dependent variable	Findings
	walked down the ramp after turn around and waiting for 1 minute while listening to music to be distracted if any possible contamination application on the floor. Recovery (again knew the floor was dry)					
12	Subjects ran with a comfortable self-selected speed that identified on the softest surface on each surface for 20 trials. The order of surface condition is randomized.	Not mention	Conventional treadmill bed Adjustable bed treadmill 2 high speed video camera (200 Hz) Reflective markers	Surface hardness • Extra hard • Hard • Medium • Soft	• Ankle acceleration • Knee acceleration • First maximum rear foot angle (P1) • Second maximum rear foot angle (P2) • Minimum knee joint angle (K) • Time to P1 relative to stance • Time to P2 relative to stance • Time to K relative to stance	No significant different for kinematics or temporal group – subjects did not accommodate to the varying surface hardness via a neuromuscular response strategy. P1 highly correlated with P2 Significant relationship observed between P1 with ankle and knee acceleration. Significant group effect – among vertical deceleration value for both ankle & knee joints.

Table 3 Rating score for the assessment of methodological quality from reviewed articles

No	Study	Question														Total score	Overall percentage	Rank
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
1	W.R Chang *et al.*	1	2	2	0	2	2	2	0	2	2	2	2	0	1	20/28	71.4	7
2	G.Strutzenberger *et al.*	2	2	2	2	2	2	2	0	2	2	2	2	1	2	25/28	89.3	1
3	Gates *et al.*	2	2	2	0	2	2	2	0	2	1	2	2	2	2	23/28	82.1	4
4	R. Muller *et al.*	2	2	2	2	2	2	2	0	2	2	2	2	0	1	23/28	82.1	4
5	J.R. Watt *et al.*	2	2	2	0	2	2	2	0	1	2	2	2	2	2	23/28	82.1	4
6	J.C. Menant *et al.*	2	2	2	0	2	2	2	0	2	2	2	2	2	1	23/28	82.1	4
7	E.S Chumanov *et al.*	2	2	2	0	2	2	2	0	2	1	2	2	1	2	24/28	85.7	2
8	P.O. Riley *et al.*	2	2	1	0	2	2	2	0	2	N	2	2	0	1	18/26	69.2	8
9	M.J.Maclellan& A.E. Patla	2	2	2	0	2	2	2	0	2	2	2	2	0	2	22/28	78.6	5
10	S.B. Thies *et al.*	1	2	1	0	2	2	2	0	2	N	2	2	2	1	19/26	73.1	6
11	R.Cham& M.S. Redfern	2	2	2	2	2	2	2	0	2	N	2	2	0	2	22/26	84.6	3
12	N.Stergiou& B.T. Bates	2	2	2	0	2	2	2	0	2	2	2	2	1	1	22/28	78.6	5

2 = Yes, 1 = Limited details, 0 = No, N = Not applicable

Table 4 Participant's characteristic

	Study	No of participant	Gender		Age (years)	Height (cm)	Weight (kg)	Category
			Male	Female				
1	W.R Chang *et al.*	29	13	16	Male = 24.3 ± 9.4 Female = 30.9 ± 10.8	Male = 179.3 ± 8.1 Female = 163.0 ± 7.8	Male = 80.3 ± 14.0 Female = 62.0 ± 9.2	-
2	G.Strutzenberger *et al.*	8	0	8	21.5 ± 2.1	162.8 ± 7.1	66.0 ± 8.5	Football players (athlete)
3	Gates *et al.*	15	12	3	22.5 ± 5	171.0 ± 9.0	76.6 ± 11.6	Ordinary & healthy
4	R. Muller *et al.*	9	9	0	24.1 ± 2.8	180.0 ± 5.0	74.1 ± 9.8	Active person
5	J.R. Watt *et al.*	18	6	12	70.3 ± 4.8	-	-	Ordinary & healthy
6	J.C. Menant *et al.*	36	Young = 4 Old = 14	Young = 6 Old = 12	Young = 27.4 ± 2.5 Old = 78.5 ± 4.2	-	-	Specific characteristic (health, walking habit)
7	E.S Chumanov *et al.*	34	17	17	Male = 22.0 ± 4.8 Female = 24.9 ± 4.8	Male = 182.3 ± 8.0 Female = 165.9 ± 8.5	Male = 79.8 ± 13.0 Female = 60.1 ± 5.9	Experienced runner
8	P.O. Riley *et al.*	26	13	13	-	-	-	Ordinary & healthy
9	M.J.Maclellan& A.E. Patla	8	5	3	20.6 ± 1.7	-	66.2 ± 15.2	Ordinary & healthy
10	S.B. Thies *et al.*	24	0	Young = 12 Old = 12	Young = 22.2 ± 3.0 Old = 70.2 ± 4.1	-	<136	Ordinary & healthy
11	R.Cham& M.S. Redfern	16	8	8	23.0 ± 4.00	173.0 ± 7.00	68.7 ± 6.80	Ordinary & healthy
12	N.Stergiou& B.T. Bates	5	5	0	22.8 ± 2.17	182.2 ± 8.61	69.9 ± 36.04	Recreational runner

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