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BME41118 - Capstone Project

Biomechanical gait evaluation of
the effects of colored medial arch support
on running on inclined surface

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Abstract

Background

Running is a popular recreational exercise because of its convenience. However, athletes often experience running-related injuries due to the high repetitive loading. As such, manufacturers often prescribe orthotic insoles in footwear and advertise their products with the benefit of injury prevention. Medial arch support inserts are commonly used as it is believed to control foot pronation and may reduce the risk of injuries effectively. Furthermore, color psychology was found to enhance the effectiveness of muscle strength training and it is speculated that colors may lessen the possibility of injuries by altering the biomechanics of runners. In addition, inclined running is frequently used for endurance training purpose and the biomechanics change with various inclinations. It is implicated that biomechanics related to injuries may change differently with the effect of inclinations and designs of insoles. Due to these reasons, further investigation is needed.

Method

Fourteen male recreational runners ran with different tested conditions on the treadmill in 3 ms⁻¹ and their running biomechanics were collected. Three treadmill inclinations (0°, 3° and 6°) and four insoles designs (flat insoles in white and medial arch support in red, blue and white) were tested. VICON Nexus 2.5 system and Bertec Fully Instrumented Treadmill were used to collect kinetic and kinematic data respectively. Ground reaction force, maximum loading rate, ankle and knee joint kinematics and spatial-temporal parameters were included. Data were then normalized and analyzed using Visual 3D. Two-way analysis of variance with repeated measures followed by LSD post hoc test were used for statistical analysis and comparisons were made between different designs of insoles and treadmill inclinations.

Results

Ground reaction force, maximum loading rate, vertical oscillation and inversion-eversion range of motion reduced significantly with the increase of inclinations. Contact time, dorsiflexion in initial contact and stride frequency were found to increase significantly with steeper slopes. With the application of medial arch support, statistically significant increases were noted in dorsiflexion in initial contact, maximum eversion, contact time and knee flexion range of motion as well. However, differences were not observed among different colors of arch support.

Conclusion

Different biomechanical parameters were compared and findings imply that colors of insoles do not contribute to the biomechanics of runners. Regarding the clinically insignificant difference in all tested parameters, it was shown that the effect of medial arch support on injuries-related parameters is limited. However, results also showed injury-related forces, vertical oscillations, ankle instability were reduced with the increase of inclinations. It can be concluded that the influence of different designs of insoles on biomechanics of runners is insignificant, but inclined running appears to improve the biomechanical parameters that associated with running-related injuries.

Acknowledgment

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List of Abbreviations

ANOVA	Analysis of variance
ASIS	Anterior superior iliac spine
Cog	Center of gravity
GRF	Ground reaction force
MLA	Medial longitudinal arch
PSIS	Posterior superior iliac spine
ROM	Range of motion
RRI	Running-related injuries
SF	Stride Frequency
SL	Stride length
STJ	Subtalar joint

Chapter 1. Introduction

1.1 Running

Sports activities and exercises are known to have a positive influence on individuals' health. Running is frequently used as a kind of physical activity and exercise because of its easy accessibility. However, due to the mixture of kinematic and kinetic forces involved over running, runners frequently experience lower-extremity injuries (Almeida et al., 2015; Gent et al., 2007). Additionally, fatigue is highly associated with RRI as it influences neuromuscular output and kinetics of the athletes, which increases the risk of injury (Schmidt, 2013; Willem et al., 2012). As insoles are believed to alter the biomechanics of lower extremities, it is widely prescribed in sports shoes as to prevent RRI.

1.2 Motivation

As a result of the repetitive loading on lower extremities, overuse injuries are commonly seen during exercise in particular to running. The relationship between foot orthoses, biomechanical parameters and the occurrence of injury have been proposed and shoes inserts with medial arch support are commonly found in sports shoes as to reduce the occurrence of RRI. Medial arch support is frequently prescribed to flatfoot patient for the support of collapsed arch. However, abnormal increased plantar pressure is observed when normal subjects wear medial arch support insoles. As such, medial arch support may adverse to normal runners. Additionally, the color of insoles may contribute to the risk of injury because color psychology is found to influence sports performance through improving muscle strength and perception of runners. Specific color might reduce the risk of injury by alleviating the occurrence of fatigue in running. Apart from insole designs, treadmill inclinations are also considered as the factors of RRI. With the increased inclinations, biomechanics of runners alters and the effect of medial arch support might be varied among different slopes. Hence, it is important to investigate the impact of insole designs and inclinations on running biomechanics in order to provide additional reference for the design of insoles and prevent RRI effectively.

1.3 Method

Fourteen male recreational runners were recruited in the study. Four pairs of insoles with different designs were given to subjects and inclinations in 0°, 3°, 6° were investigated. Subjects were instructed to run on the treadmill with the tested insoles and inclinations in 3 ms⁻¹ while kinetics and kinematics data were recorded. Data from ten strides were captured and averaged. The biomechanics of runners with different insoles designs and inclinations on treadmill running were calculated and compared.

1.4 Objective

The aim of conducting this project is to examine the influence of medial arch support insoles of various colors on the biomechanical parameters related to RRI in running on inclinations.

Chapter 2. Literature Review

2.1 Running-related injuries (RRI)

Running is a prevalent recreational exercise and believed to enhance physiological and psychological health. However, runners often develop overuse injury as a result of running. RRI are not clearly defined while various research has explained them as musculoskeletal ailments that lead to restriction of running performance (Hreljac, 2004). Different studies have been conducted on the prevalence of RRI. Depending on the population of runners studied, 27% to 70% of recreational and competitive runners have reported the incidence of overuse injuries within one year and approximately 6.8 to 59 injuries are occurred per 1,000 hours of exercises (Ferber et al., 2009; Saragiotto et al., 2014).

Running is characterized by the repetition of movements with few variations. Therefore, the majorities of RRI are cumulative micro-trauma injuries and classified as overuse injuries (Hreljac, 2004; Malisoux et al., 2013). Stress fractures, medial tibial stress syndrome, iliotibial band syndrome and plantar fasciitis are included. The etiology of RRI is multifactorial, with training, anatomical and biomechanical factors contributing. Regarding the observation of clinical studies, over 60% of RRI were due to training errors (Hreljac, 2004). Athletes who stretch regularly before running demonstrated a higher injury rate than those who did not (Rochcongar et al., 1995). Besides, anatomical and biomechanical features of runner also contribute to the occurrence of overuse injury. Lower extremity abnormalities have been implicated as one of the factors for RRI. However, contradictions were found on leg length discrepancies and excessive Q-angle among previous research (Pollard et al., 2002). Inconsistencies in findings may be due to the biomechanical variables as kinetics and kinematics vary to affect individuals significantly. Biomechanical factors can be classified into kinetics and kinematics. GRF, rate and magnitude of impact forces are suggested to be closely associated with RRI. Ferber et al. (2002) reported that females with stress fracture history demonstrated greater peak vertical GRF and loading rates than uninjured subjects. Similar findings are found in the study of Hreljac et al. (2000) with runners in both sexes were included. Regarding the evaluation of clinical studies, greater pronation and pronation velocities were observed in injured runners when compared to the uninjured group. As pronation allows impact forces to be reduced through a protective mechanism, kinetics and kinematics that leads to RRI are closely related (Hreljac, 2004).

Fatigue in prolonged running attributes to RRI through the influence of biomechanical variables as well. Fatigue delays muscle activation and changes kinematics and kinetics of runners adversely. Alterations in impact forces and ground reaction force were also reported by previous studies and these changes are associated with RRI biomechanically (Baker et al., 1972; Mizrahi et al., 2000). Besides, impact acceleration on shank and muscle activity imbalance increase with the progression of tiredness and these alterations result in a higher risk of stress injury (Mizrahi et al., 2000).

Alterations in biomechanical variables are generally accepted as one of the factors in RRI. As such, the evaluation of kinetics and kinematics is essential for the consideration in the prevention of RRI.

2.2 Insoles

Preventing risk of RRI and improving running performance are the common concerns for runners. Different sportswear is examined and research has been conducted to attain these goals. Compression garments can minimize overuse injuries through heating effect and the reduction of eccentric-induced muscle damage (Dascombe et al., 2011). Likewise, insoles are extensively used in sports as to reduce fatigue through minimizing the plantar loading (O'Leary et al., 2008). With the application of insoles, people with flatfoot are found to be less fatigue when uphill walking and impact forces are reduced for normal subjects (Huang et al., 2017). Insoles are associated with the reduction of RRI-related parameters in level running and biomechanical variables are influenced by insoles when uphill walking. However, limited research has been conducted on the effect of inserts in the uphill running. Therefore, the relationship between insoles and uphill running in healthy subject is still unclear and needed to be investigated.

A shock wave is transmitted when foot contacts ground in running and the load of running is 1.5 to 5 times of body weight. These high loads are repetitively absorbed when running (Lucascuevas et al., 2016; Hreljac, 2004). It is suggested that the repeated loading and associated impact shocks might damage the underlying tissues and increase lower extremities stiffness. This further reduces shock attenuation and result in overuses injuries, such as stress fractures, shin splints, and plantar fasciitis (Milner, 2006; O'Leary, 2008). To alleviate the occurrence of fatigue and prevent RRI, insoles are commonly used due to its influence on biomechanical parameters. O'Leary et al. (2008) have investigated the influence of cushioned insoles on biomechanical factors and the findings demonstrated the reduction of impact force and tibial acceleration at initial contact in shock-absorbing insoles. As these parameters are closely related to RRI, it is believed insoles contribute to the protection of runners. Similar findings were also suggested by House et al. (2013) and the incidences of RRI with the application of cushioned insoles were recorded. Additionally, lateral wedge insoles are usually prescribed to individuals with medial knee osteoarthritis. Reduction of knee adduction and varus moment were noted with the wedged orthoses. This reduces the load in medial compartment of knee joints and may alleviate the discomfort of individuals with knee osteoarthritis (Butler et al., 2007; Kakihana et al., 2005). Besides, insoles with medial arch support demonstrate its effectiveness on the control of pronation in previous studies as well. Pronation is a combination of ankle dorsiflexion, foot eversion and abduction (Kim, 2015).

To restore normal eversion and pronation in flatfoot patient, medial arch support insoles are often recommended. Findings of previous studies show that the eversion angle was reduced by 3.1° for pronator subjects in running. In addition, 84% of pronators had restored their normal eversion range in running with the application of orthoses (Fong et al., 2008). Research demonstrated the alterations of biomechanical parameters with respect to insoles clearly and some of the investigated factors are closely related to RRI. As such, the association of insoles and RRI-related parameters should be further investigated.

Footwear manufacturers integrate orthotic inserts in their product and advertise their effectiveness on protection and compensation of the deficiencies of runners' foot. Regarding the findings in previous research, medial arch support is commonly prescribed and used to support the MLA of runners. Their influence on biomechanics and protective effect against overuse and traumatic injuries have been widely investigated (Bonanno et al., 2016; Saadah et al., 2015). With the application of medial arch support, reduced peak pressure were observed in static and dynamics situation. Besides, peak impact force and knee internal rotation angle are lowered when playing basketball as well (Zhang et al., 2017; Zong et al., 2016). Regarding the findings in previous studies, medial arch support insoles alter the biomechanics of athletes and it was implicated for the prevention of RRI effectively based on questionnaire data from user experience and results are controversial (Aaltonen et al., 2007; Esterman & Pilotto, 2005). Therefore, biomechanical evaluation of the medial arch support is urgently required.

2.3 Uphill running

There are different factors that affect biomechanical parameters of runners, including environment and geographic (Padulo et al., 2013; Saunders et al., 2004). Environmental factors refer to dehydration and altitude. Geographical factors are the variations in running surfaces and inclination is included. Kinetics and kinematics vary between level and uphill running. Research has suggested uphill running is associated with increased metabolic cost (Padulo et al., 2013). To maintain the constant speed during uphill running, the reduction in step length with concomitant increases in step frequency are adopted. Additionally, GRF reduced when the treadmill inclines. On the 9° incline, parallel braking force peaks were 78% less than level running (Gottschall & Kram, 2005). Kinematics are altered by inclination as well. Plantar-flexion angle is reduced, while hip and knee flexion angles are increased in the uphill running (Devita et al., 2008; Kowalski & Li, 2016; Park et al., 2014).

Various studies have investigated the effect of inclinations to RRI. With the alterations of biomechanical factors, metabolic demand increases with inclinations and it was concluded that uphill running induces injuries due to the increase of metabolic cost. Besides, inclined running was speculated with the greater incidence of injuries to plantar fascia due to the changes in plantar fascia strain (Sinclair et al., 2014). Yet, contradictions are found with the findings of Gottschall and Kram (2005). The influence of insoles in level running has been widely examined as well. It can be concluded that insoles protect runners from overuse injury as it alters biomechanical parameters of runners and the injury-inducing forces are reduced with the application of insoles (Sinclair et al., 2014). Although the changes of biomechanical variables in the uphill and level running are well-documented, the influences of inclinations to RRI-related biomechanics are still unclear. Besides, it is suggested that biomechanical parameters change with the applications of medial arch support. As such, it is necessary to examine the effect of shoes inserts towards biomechanical parameters that associated with RRI in different inclinations.

2.4 Color

Color is a ubiquitous perception and considered as the aesthetics status over the globe. It is believed to be highly associated with emotions and behavior under the repetition of daily encounters (Elliot et al., 2007; Elliot, 2015). It is expected to manipulate and influence the psychological operation without any individual's conscious intention. Red is generally recognized as romance, while black and blue are perceived as sadness and fear respectively (Hanada, 2012). To facilitate individual's performance, relevant research has been conducted and the psychological functions of coloration have been applied to multidisciplinary areas (Elliot et al., 2007; Hill & Barton, 2005).

Different studies were conducted to investigate the psychological effect of color on physiological performance. Red is believed as the most influential color and combat sportsmen are expected to perform better when dressed in red (Attrill et al., 2008; Feltman & Elliot, 2011; Hill & Barton, 2005). As red is regarded as the testosterone-dependent signal for the male, it induces the perception of superiority and threat. A menacing effect will be emanated on opponents and dominance will be enhanced in athletes with red sportswear (Rowe et al., 2005). The corollary that red benefits sports performance is supported by previous research that investigates the performance of athletes in different colors of outfits (Hagemann et al., 2008; Krenn, 2014). However, inconsistent results have been noticed in enhancing cognitive task performance. Some researchers suggest that performance can be improved by blue instead of red (Elliot et al., 2007; Sinclair et al., 1998), while Hatta et al. (2002) have the opposite findings. Regarding the previous research, studies on color effect are mainly focusing on the performance in combat sports (Attrill et al., 2008; Hill & Barton, 2005; Krenn, 2014). However, limited research has considered the effect of color on non-combat sports performance (Rezaeian et al., 2015). Therefore, the effect of color on running is still unclear and should be explored.

Regarding the findings of previous studies, muscle strength is found to be influenced by color psychology as well (Crane et al., 2008; Dreiskaemper, 2013; Elliot & Aarts, 2011). Athletes with red attires demonstrate a greater strength development when compared to other colors (Elliot & Aarts, 2011; Payen et al., 2011). Besides, higher heart rate and strength are also indicated with red jersey (Dreiskaemper, 2013). These findings are in agreement with the conclusion of Elliot and Aarts (2011) that the magnitude and velocities of pinch grip and

handgrip forces were facilitated under red light conditions. The influence of colors on muscle strength has been widely investigated and alterations of biomechanical variables are involved.

Several studies have been conducted on the relationship of muscle strength and running economy. Runners are found to experience a longer time to exhaustion at maximal aerobic speed and better running economy after the training of muscle strength (Guglielmo et al., 2009; Storen et al., 2008). As the effectiveness of muscle strength training are influenced by colors and muscle strength is closely related with running economy, it is speculated that colors may contribute to running economy and possibly reduce the occurrence of fatigue in running. According to the findings from previous scholars, RRI can be induced by the biomechanical changes in fatigue states. Conducted by Milgrom et al. (2002), bone strains are increased in fatigue condition and may be attributed to the stress fracture etiology. Besides, kinematics alters with the development of fatigue. Fatigue runners exhibit higher impact acceleration and muscle imbalance in the shank. This hampers the loading balance of tibia and results in a higher chance of stress fractures (Mizrahi et al., 2000). As abductor hallucis is disrupted in fatigue, pronation increases and this raises maximum loading rate significantly and leads to plantar fasciitis (Pohl et al., 2009). As such, the link between colors and biomechanical parameters related to RRI can be further proposed based on the speculation of the relationship between colors and fatigue. Yet, limited research has been conducted and thus, the association between color psychology and RRI-related factors with respect to fatigue should be investigated.

Chapter 3. Methodology

3.1 Participants

Fourteen male recreational runner participated in this study (age = 21.2 year $\pm$ 1.97, height = 1.79 m $\pm$ 0.03, weight = 74.4 kg $\pm$ 3.51, mean $\pm$ standard deviation). A subject number was assigned to each participant for identification. An anonymous screening form (Appendix III) was used to record the participants' personal information as a reference. Besides, participants were asked to report whether they have lower extremity injuries six months prior to the study. Potentially ankle, knee, hip and spinal problems, systemic diseases, neurological defects, motor and cognitive disorders were absented from all selected subjects. Arch index was calculated before study participation and only individuals with normal foot arch were selected. Additionally, participants were asked to conduct the Ishihara Color Blindness Test prior to the study (Marey et al., 2015). Only participants with all answered correctly were included in the study (Appendix III & IV). Consent and information sheet were distributed and signed respectively before the study (Appendix I & II).

3.2 Arch Index Calculation

The arch index was used to classify footprint in this study. Harris mat was used to obtain the footprint of the participants. Toes were excluded from the calculation and the remaining footprint was divided into three equal parts. The AI was then calculated as the area of the middle third divided by the entire footprint area. The arch index between 0.21 and 0.28 is regarded as normal foot arch (Cavanagh & Rodgers, 1987; Menz et al., 2012).

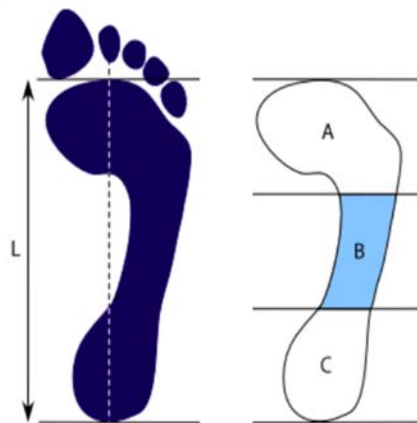


Figure 1. Arch index calculation.

(Retrieved from: <https://jfootankleres.biomedcentral.com/articles/10.1186/1757-1146-5-10>)

3.3 Equipment and Apparatus

3.3.1 Treadmill Setting

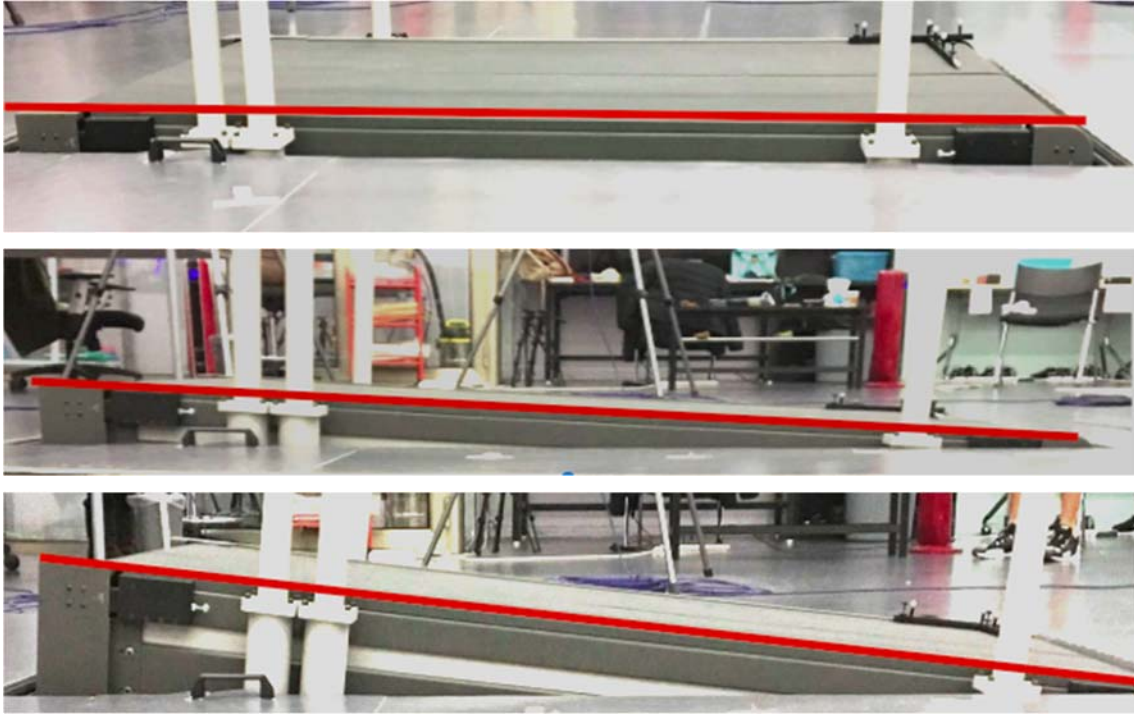


Figure 2. Treadmill in 0°, 3°, 6° (from top to bottom).

Bertec Fully Instrumented Treadmill was used in this study and it was sampled at 1000Hz. Two independent force measuring running belts were mounted on the treadmill. Belt and incline control functions were included in the control panel. Belt control was used to direct the belt speed and acceleration while incline control was used to control the inclination when the “Homed” function was activated (Appendix VIII). 0° (0%), 3° (5.24%), 6° (10.5%) were chosen in this study (Gottschall & Kram, 2005; Snyder et al., 2012) (Figure 2). AM6501 analog amplifier was utilized to convert the digital output of the treadmill force plates to analog. To ensure the accuracy, the treadmill was calibrated and checked before each section according to the instructions of the manufacturer.

3.3.2 Insoles



Figure 3. White, blue and red insoles with medial arch support (from left to right).



Figure 4. With (top) and without (bottom) medial support insoles.

Table 1. Insoles design.

Insoles	1	2	3	4
Colors	Red	Blue	White	White
Medial arch support	Present	Present	Present	Absent

Table 2. Material and component of insoles.

Insoles condition	Material	Shape
Medial arch support	Polyurethane	3 mm MLA support
Flat	Polyethylene	Flat

Four pairs of insoles were tested in the experiment. They were 1) red insoles with medial arch support, 2) blue insoles with medial arch support, 3) white insoles with medial arch support and 4) white insoles without medial arch support (Figure 3 & 4; Table 1 & 2). Red is warm color and believed to affect perception the most, while blue is opposite and found to enhance cognitive performance (Hill & Barton, 2005; Feltman & Elliot, 2011). White is chosen as it is an achromatic color and often studied in previous research (Elliot et al., 2007).

3.3.3 Running shoes

Running shoes with simple design were chosen and reflective surface was covered by 3M™ Micropore™ in order to minimize errors during data collection. Two pairs of running shoes and two sets of insoles with different sizes (43 and 44) were prepared. Brannock device was used to measure the foot length of the participants and the appropriate size of shoes and insoles were used in the experiment.

3.3.4 Marker placement

Forty reflective markers were used in the experiment. Six markers were placed on each shoe (Figure 6) and four markers were placed at each thermoplastic board for thighs and shanks as well. The remaining markers were placed on body prominence that near the joint centers by the same researcher as to ensure the consistency of markers placement. Medial and lateral malleolus (ankle), medial and lateral femoral condyle (knee), ASISs and PSISs were chosen. (Figure 5 & Appendix VII).

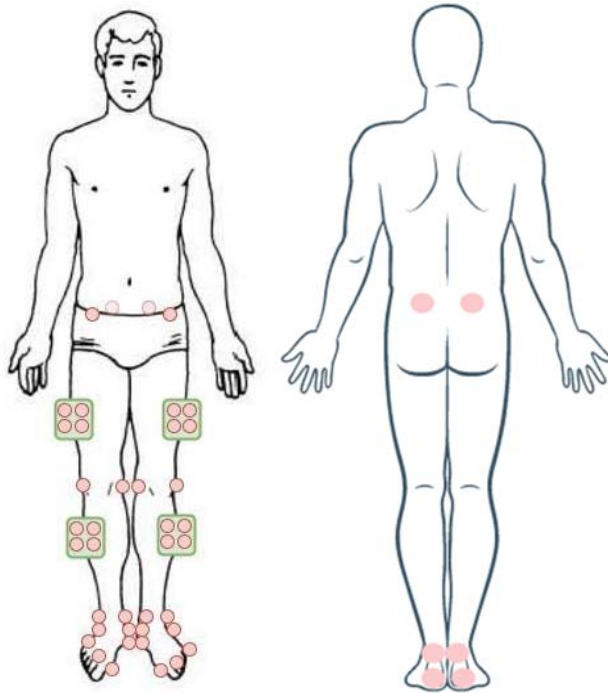


Figure 5. Marker placement front view (left) & back view (right).



Figure 6. Marker placement in running shoes front, side and back view (from left to right).

3.4 Procedures (Appendix VI)

The experiment was conducted in the biomechanics laboratory of the Li Ning Sports Science Research Centre. Lighting was controlled and natural light was blocked. This was done to avoid any environmental changes that lead to bias. After finish the screening, participants were asked to sign the consent form and read the clause on it (Appendix I). An information sheet was provided and the procedure of the experiment was included (Appendix II).

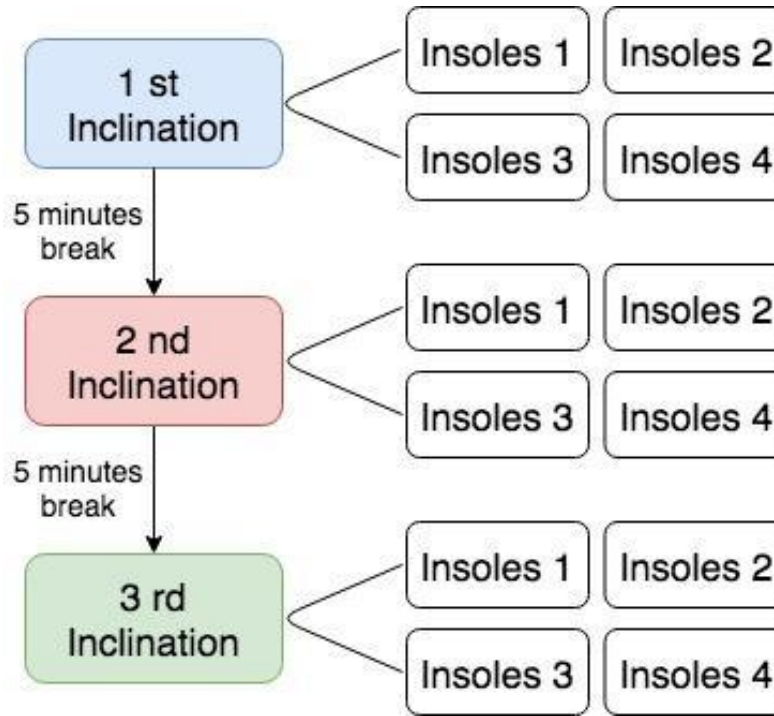


Figure 7. Experiment Protocol.

There were three testing sections with a 5-minute break in between. All insole designs with one inclination were tested in each section. The experimental sequence was randomly assigned to participants. VICON cameras were masked and calibrated prior to the experiment. Subjects were asked to run with their preferred speed and inclinations on the treadmill for five minutes prior to data recording in order to familiarize with the sports shoes and treadmill. Upon warm-up, the tested insoles were shown and changed for the participants. Refractive markers were attached as shown in figure 5 and subjects were then asked to stand still with arms held laterally for static alignment recording (Appendix VII).

There were four running trials in each section. One insoles design was tested in each trial and randomized testing order was adopted. Participants were then instructed to run on the force treadmill with different conditions at 3 ms^{-1} (Gottschall, & Kram, 2005; Kowalski & Li, 2016; Snyder et al., 2012). 1 minute was given for the accommodation of insoles and slopes before the data recording and a 10-second recording with approximately 10 consecutive strides were obtained (Hunter & Smith, 2007). Upon the completion of one trial, subjects were asked to wear the next randomized designs of insoles and completed the experiment with the same procedure until all the insole designs of the same inclination were tested. Participants were then asked to run with different inclinations until all combinations of

insoles designs and inclinations were completed. A total of 168 trials (14 subjects $\times$ 4 different designs $\times$ 3 different inclinations) were obtained for data analysis. The experiment for each participant was taken for 2 hours.

3.5 Tested parameters

Table 3. Tested parameters in the study.

Biomechanical parameters	Description	Units
RPEAK	Peak vertical ground reaction force	BW
MAX LD	Maximum loading rate in stance phase	BW/s
Vertical oscillation	Maximum displacement of center of gravity	m
Contact time	Contact time in stance phase	s
SL	Stride length	m
SF	Stride frequency	Hz
xA @ TD	Ankle Angle in sagittal plane at initial contact	Degree
xA @ TF	Ankle Angle in sagittal plane at toe off	Degree
IE ROM	Inversion and eversion range of motion in stance phase	Degree
MAX EVERSION	Maximum eversion in stance phase	Degree
xK @ TD	Knee Angle in sagittal plane at initial contact	Degree
xK @ TF	Knee Angle in sagittal plane at toe off	Degree
KF ROM	Knee flexion angle range of motion in stance phase	Degree
MAX KB	maximum knee flexion angle in stance phase	Degree

Various biomechanical parameters were used to evaluate the risk of RRI with different inclinations and designs of insoles. Repetitive loading of the musculoskeletal system is suggested to be involved in the underlying mechanism of the majority of RRI. Under the same running speed, a lower peak GRF implies less loading is involved and contributes to safety of running (Malisoux et al., 2013). Maximum loading rate is found to be closely related to lower-extremities stress fracture and muscle fatigue during runner as well (Christina et al., 2001; Zadpoor & Nikooyan, 2011). With the reduction of loading rate, runners are less likely to be injured. Running speed can be defined by SL and SF (Hunter & Smith, 2007). To reduce the risk of sports injuries, increasing of SF and decreasing of SL are suggested (Schubert et al., 2013). It is suggested that the reduction of vertical oscillation will reduce the impact loading that ankle and knee joint required to absorb and thus minimize the possibility of RRI (Heiderscheit et al., 2010; Willy & Davis, 2014). RRI is influenced by kinematic factors as well. Studies have been conducted on the comparison between injured and uninjured runners. It is suggested reduced peak ankle eversion angle is observed to be related to less RRI (Christina et al., 2001). Evidence has shown that RRI is related to the instability of ankle joint as well. This can also be minimized through smaller ankle inversion-eversion ROM as well (Tsujimoto et al., 2016). As such, a reduction in inversion-eversion ROM can also enhance running safety. Dorsiflexion is considered as one of the kinematic changes that leads to pronation and thus, overuse injuries. Additionally, runners ran with greater knee flexion angle when they were tired (Miller et al., 2007). Therefore, kinematics of knee joints is also included as the testing parameters in order to evaluate the risk of injuries in term of fatigue.



Figure 8. Laboratory Setup.

3.6 Data Collection

Different equipment was employed to appraise the above parameters. A force plate mounted treadmill was utilized to record the kinetic data with sampling rate at 1000Hz. Peak vertical GRF and maximum loading rate were collected in the ratio of body weight. A 10s of force data was collected after 1 minute of accommodation. The last 10 consecutive stances were cut and averaged for analysis (Hunter & Smith, 2007). Stance phase was defined as heel strike of one foot to heel strike of another foot and identified as the first data point that force was greater than 20 N after swing phase, where $F=0$ N (Hunter & Smith, 2007).

Stride cycle was identified from the vertical ground reaction force generated by the right leg (Schache et al., 2011). One stride was counted from the start of one stance phase to the moment before the next stance phase. Calculations were done to obtain spatiotemporal factors as well. SF was calculated from the obtained force data. The number of frames for one stride in ten consecutive strides were averaged and calculated as SF. SL was then estimated by dividing the treadmill speed by SF (Mercer et al., 2002; Moore et al., 2014; Swanson & Caldwell, 2000).

$$SF \text{ (Hz)} = \frac{1}{\text{Avg. time for 1 stride among 10 consecutive stride (s)}}$$

$$SL \text{ (m)} = \frac{\text{Treadmill Speed (ms-1)}}{SF \text{ (Hz)}}$$

VICON Nexus 2.5 system with eight cameras was also employed to capture the kinematic data. Refractive markers were recorded by the camera at 200 Hz. With the marker placement as mentioned, kinematics data of the subjects were captured for data analysis.

3.7 Data Analysis

Kinetic and kinematics data were filtered by Butterworth filter with cut-off frequencies 100 Hz and 12 Hz respectively (Fellin et al., 2010; Nigg et al., 2003; Roy & Stefanyshyn, 2006). The filtered data were normalized and calculated using Visual 3D (C-Motion).

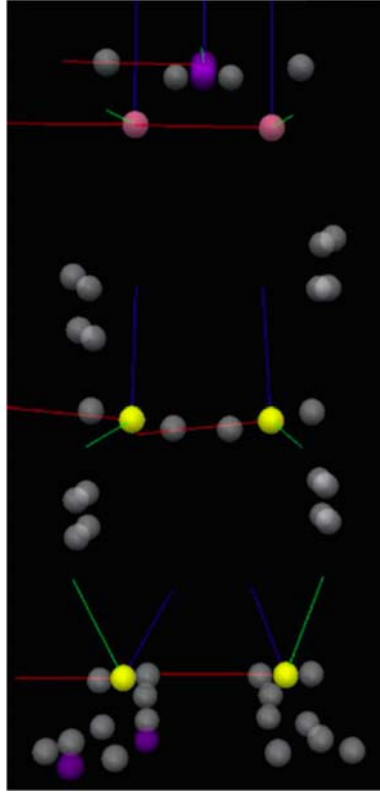


Figure 9. Four-segment right leg model.

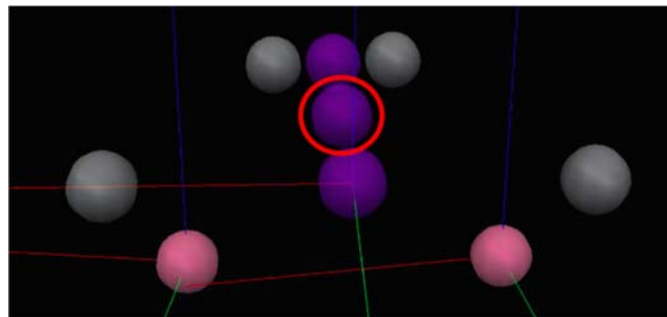


Figure 10. Virtual point (circled in red) in intersection of ASISs and PSISs.

A four-segment right leg model was built with ankle, knee and hip joints located by colored markers (Figure 9). Foot segment was established through the projections of the heel and second metatarsal markers (purple markers in Figure 9). A virtual point in the intersection of ASISs and PSISs was added to indicate the Cog (Figure 10) and vertical oscillation was calculated by finding the greatest displacement of Cog throughout the stance. SL and SF were

found directly by calculations with the use of the mentioned equation. The pipeline was used to locate different events in stance phase by adjusting window frames and threshold values. Peak GRF, the start and end of the stance phase were identified on the force-time graph (Figure 11). Kinematics of ankle and knee joint in initial contact and toe off were also included and analyzed. These data were then compared to different designs of insoles and inclinations.

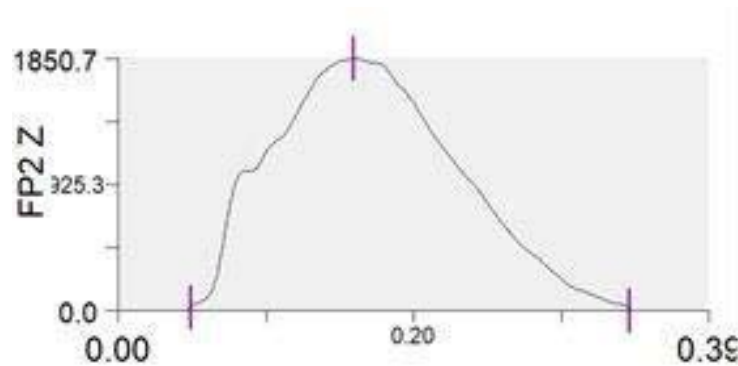


Figure 11. Force-time graph with events located in Visual 3D.

3.8 Statistics Analysis

IBM SPSS statistical software (version 22.0.0; IBM Corporation, Armonk, New York, USA) was employed for data analysis. Two-way ANOVA with repeated measures was used to compare the acquired data in order to evaluate the influence of different designs of insoles on the biomechanics parameters related to RRI. The independent variables of this experiment were the design of insoles and the inclinations of the treadmill, while the dependent variable was the biomechanical factors obtained in the study. Insoles with different designs were analyzed through a two-way ANOVA with repeated measures. However, main effects were not significant in all testing parameters. As colors and configurations of insoles were different among the four tested insoles, the acquired data were influenced by two factors when all insoles were compared at the same time. To avoid any discrepancies caused, two-way ANOVA with repeated measures were then conducted on different colors of insoles and the use of medial arch support separately.

Prior to the two-way ANOVA with repeated measures, the interaction between two independent variables was determined. Significance value below 0.05 ($p < 0.05$) was considered as significant interaction and the main effect could not be determined through two-way ANOVA with repeated measures directly. One-way ANOVA with repeated measures was then performed. Mauchly's test and Shapiro-Wilk test were performed prior to the analysis in order to verify the sphericity and normality of data respectively. LSD Post-Hoc test was then performed to determine the significant difference of the acquired data and significance value below 0.05 ($p < 0.05$) was considered to be significant.

Chapter 4. Results

To prevent any bias caused by colors, only medial arch support inserts in white color was compared with the flat insoles. Meanwhile, the effect of insoles color was assessed between medial arch support insoles in red, blue and white color.

4.1 Different inclinations

Table 4. Biomechanical parameters under different inclinations.

Parameters	Slopes						<i>P-value</i>
	0°		3°		6°		
	Mean	SD	Mean	SD	Mean	SD	
Ground reaction force (BW)	2.36*	0.072	2.30*	0.067	2.28*	0.061	0.000
Maximum loading rate (BW/s)	112*	6.27	91.2*	5.02	77.7*	4.86	0.000
Vertical oscillation (m)	0.0800*	0.004	0.0800*	0.004	0.0700*	0.004	0.000
Contact time (s)	0.25*	0.003	0.260*	0.003	0.26*	0.004	0.001
Ankle Angle in sagittal plane at initial contact(deg)	2.40*	1.17	5.97*	0.958	9.01*	1.05	0.000
Stride frequency (Hz)	1.44*	0.026	1.45*	0.030	1.47*	0.033	0.049
Inversion-eversion range of motion (deg)	10.3*	0.730	9.00*	0.551	8.27*	0.505	0.001

*. Mean difference is significant at .05 level

The statistical results showed that GRF, maximum loading rate, vertical oscillation and inversion-eversion ROM reduced significantly with the increase of inclinations. Meanwhile, contact time, ankle angle in sagittal plane at initial contact and SF increased significantly with steeper slopes.

4.2 Present of medial arch support

4.2.1 Two-way ANOVA with repeated measures

Table 5. Biomechanical parameters under the absent and presence of medial arch support.

Medial Arch Support					
Parameters	Present		Absent		P-value
	Mean	SD	Mean	SD	
Ground reaction force (BW)	2.32	0.065	2.30	0.067	0.344
Maximum loading rate (BW/s)	96.3	5.32	91.4	4.20	0.955
Vertical oscillation (m)	0.080	0.004	0.070	0.004	0.073
Contact Time (s)	0.260*	0.003	0.250*	0.003	0.001
Ankle Angle in sagittal plane at initial contact (deg)	6.27*	1.10	5.31*	0.933	0.014
Knee Flexion ROM (deg)	-24.3*	2.28	-23.2*	2.16	0.000

*. Mean difference is significant at .05 level

With respect to the statistical data, it is noted that runners ran with longer contact time, larger dorsiflexion in initial contact and greater knee flexion range of motion with the use of arch support inserts. Additionally, GRF and maximum loading rate increased with the presence of medial arch support. However, no significant difference ($p > 0.05$) was found between the use of arch support.

4.2.2 One-way ANOVA with repeated measures

4.2.2.1 Maximum Eversion Angle

Table 6. Maximum eversion angle (deg) under the absent and presence of medial arch support.

	Medial Arch Support				
	<i>Present</i>		<i>Absent</i>		<i>P-value</i>
	Mean	SD	Mean	SD	
0°	-12.3*	2.70	-11.2*	2.85	0.040
3°	-10.5	2.18	-11.0	1.61	0.181
6°	-12.4*	2.08	-11.5*	2.07	0.000

*. Mean difference is significant at .05 level

As significant interaction was found between inclinations and medial arch support ($p = 0.008$), one-way ANOVA with repeated measures was performed. Statistically larger maximum eversion angle was observed when runners ran with the medial arch support inserts.

Chapter 5. Discussion

5.1 Summary and critical appraisal of work done

In this study, biomechanical parameters of various insoles design and inclinations were evaluated. Prior to the conduction of experiment, literatures were reviewed to identify the clinical gap and ensure the feasibility of this study. Considerations were taken for the experimental protocol and selection of independent variables as well.

Medial arch support insoles were selected as they are commonly seen in commercially available footwear. Red, blue and white colors of insoles were also tested in this study. Red and blue were selected as they are believed to affect perception and improve cognitive performance respectively (Feltman & Elliot, 2011; Hill & Barton, 2005). White was chosen as it is an achromatic color (Elliot et al., 2007). As these colors are frequently studied, results could be compared with the findings from previous research.

Inclinations with 0°, 3° and 6° were selected in this experiment as they are commonly used in previous study with subjects ran in 3 ms⁻¹ on treadmill (Snyder et al., 2012; Gottschall & Kram, 2005). As biomechanical parameters are influenced by slopes, it was expected that biomechanics of different design of insoles varies among the tested inclinations. Additionally, limited difference was found between treadmill and overground running and subjects can run with well-controlled and reproducible conditions with the use of treadmill (Riley et al., 2008).

Methodology was established with the reference of previous research. To identify the possible limitation in the study, a pilot study was carried out prior to the data collection. Environment was well-controlled as to avoid the unnecessary visual effect. Subjects were given standardized sports attires in black as black is an achromatic color and did not tested in this study. Prior to data collection, subjects were recruited according to the selection criteria and arch index were calculated. This eliminated the discrepancy of the acquired data. To collect the experimental data, runners were instructed to run on treadmill under different conditions and stiffness of insoles were tested before each trial. To avoid the effect of fatigue due to prolonged running, one minute adaptation and five minutes break were provided in each trial and section respectively. This increased the accuracy and repeatability of the experiment. Biomechanical parameters were captured by VICON system and only stance

phase of right leg was processed in Visual 3D. Data from ten stances were averaged prior to the analysis of SPSS as to minimize the effect of extreme values in results. A two-way ANOVA with repeated measures followed by LSD test was used to examine the interaction and difference between different independent variables. Mauchly's test was performed prior to the analysis in order to verify sphericity of data. One-way ANOVA with repeated measures was used when significant correlation was found between the tested independent variables. Shapiro-Wilk test and Mauchly's test were performed before the statistical analysis as to ensure for the normality and sphericity of the data. Transformation of normal distribution was performed to the data when the assumption of normality violated and Greenhouse-Geisser correction was performed to reduce type I error rate with the violation of assumption of sphericity. Results from previous studies were used to compare and evaluate the changes of biomechanical parameters as supporting evidence. Conclusion was drawn according to the results and findings in this study.

To complete this study, several tasks were done in order to ensure the feasibility and credibility of this study.

5.2 Results and finding

5.2.1 Slopes

Treadmill inclination was found to have statistically significant effect on GRF, maximum loading rate, vertical oscillation, contact time, ankle angle in sagittal plane at heel strike, SF and inversion-eversion ROM.

GRF and maximum loading rate were smaller in the uphill running and this finding matches the study that was conducted by Gottschall and Kram (2015). A spring-mass model was formulated by previous research and this suggests that landing velocity is responsible for the change of peak vertical GRF and maximum loading rate (McMahon & Cheng, 1990). As the treadmill inclines, runners fall closer between steps and this takes less flight time. Hence, landing velocity is lower in the uphill running (Gottschall & Kram, 2015; Iverson & McMahon, 1992). With increasing inclination, peak vertical GRF and maximum loading rate decreases as landing velocity decreases. Investigation conducted by Swanson and Caldwell (2000) suggests that runners tend to place their leg in similar position regardless of inclinations. To maintain similar foot placement in uphill running, ankle dorsiflexion is increased and findings in this study are in agreement with their research. Previous research indicates that uphill running is associated with the increase in metabolic cost because incline running raises the activity of several muscles and the vastus medialis, biceps femoris, and gastrocnemius are included (Swanson & Caldwell, 2000). Regarding the results in this study, vertical oscillation and inversion-eversion ROM were reduced with the increasing slopes. The reduction may attribute to the minimization of energy expenditure in incline running (Gottschall & Kram, 2005; Saunders et al., 2004). Additionally, results in SF are in agreement with Padulo et al. (2012). In spite of the difference of tested inclinations, SF increases to maintain constant speed in uphill running while SF is closely associated with the ground contact time. Suggested by the spring-mass model from previous studies, it is noted that contact time increases with steeper slopes. Although contact time increased statistically significant in this study, the difference among the tested inclination was 0.01s only. As such, contact time was classified as clinically significant due to its distinguishability in practical and the results is similar to Padulo et al. (2012). Increasing trend was also observed in previous studies but results were statistically insignificant different. Inconsistency of the findings may be due to the difference in subjects' running background. High-level competitive runners were recruited in the research of Padulo et al. (2012), whereas the

biomechanics of recreational runners were examined in this study. It is suggested that trained runners can acutely adopt different conditions of running with less alterations in biomechanics when compared to recreational runner. As such, statistically insignificant difference in contact time were observed from the previous studies.

Greater GRF and maximum loading rate are found to be closely related to overuse injuries (Hreljac et al., 2000). With lower forces and loading rate involved, this enhances the safety of running. Additionally, a stable running pattern is characterized by the reduction of vertical oscillation and ankle instability (Tsujiimoto et al., 2016; Willy & Davis, 2014). Increasing SF is associated with the reduction of RRI factors, such as GRF and energy absorption in hip, knee and hip joints as well (Schubert et al., 2013). As such, it is noted that biomechanical factors that related to RRI improved in uphill running when compared to level running and uphill running may potentially help to reduce the risk of RRI.

5.2.2 Medial arch support insoles

The use of medial arch support was found to have the statistically significant effect on maximum eversion angle, ankle angle in sagittal plane at initial contact, knee flexion range of motion and contact time.

Maximum eversion angle and dorsiflexion angle at initial contact increased approximately 1° with the adoption of medial arch support. Yet, the maximum eversion angles were lower than 13° , which is the normal range of healthy subjects, in both conditions (Fong et al., 2008). As the difference is physically undistinguished, findings are considered as clinically insignificantly. Pronation of STJ is a combination of calcaneal eversion, forefoot abduction, and dorsiflexion (Kim, 2012). As such, maximum eversion angle and ankle angle in the sagittal plane at initial contact are closely associated with pronation. Conducted by Rodgers and Leveau (1982), it was shown that the maximum eversion angle and dorsiflexion at initial contact were significantly reduced with the use of foot orthoses. However, findings in this study does not match with the results of previous research and this might due to the difference on subjects' conditions. Subjects were the patients of the podiatrist in previous study and they were found to have leg length discrepancies and flatfoot, but recreational runners were participated in this study and they were free from nonconformities in lower extremity. Besides, Fong et al. (2008) investigated the effect of medial arch-heel support on biomechanical parameters and maximum eversion angle was decreased significantly in normal runners. Conflicts are found between this study and previous research. This might be due to the variation of the running shoes. Regarding the previous study, reinforcement was observed in the heel counter of running shoes. In contrast, the heel counter was relatively flexible in this study as to improve the comfort of runners. Heel counter is believed to control eversion of calcaneus as it contributes to the position of STJ at heel-strike and management of calcaneal eversion in stance phase (Johanson et al., 1994). As such, maximum eversion angle might reduce with the reinforced heel counter in previous study and the insignificant findings can be attributed to the containment of calcaneus from heel counter. Likewise, dorsiflexion angles at initial contact increased due to the combined motion of pronation. However, findings on ankle kinematics are clinically insignificant ($< 1^\circ$) as differences are unobservable in clinical evaluation.

Regarding the difference in results obtained, kinematic of knee joint was found to be affected by the presence of medial arch as well. Knee flexion ROM increased by approximately 1° with the arch support. However, findings were clinically insignificant because the alteration in knee flexion ROM was hardly observed practically and the effect of the slight difference in knee flexion ROM toward RRI was limited. The findings on the kinematics of knee are similar to the conclusions of Lafortune et al. (1994) and Nester et al. (2003). Regarding the findings of Nester et al. (2003), the effect of orthoses was mainly observed at the rearfoot complex, whereas minimal changes were found in knee kinematics and none of the related findings were statistically significant. Lafortune et al. (1994) suggests that the changes of knee joint kinematics is due to the compensation of ankle kinematics alteration. Yet, limited alterations were found in ankle kinematics in this study and thus, clinically insignificant was observed. Additionally, previous research studied the kinematic changes of subjects in walking, whereas the biomechanics of runners were investigated in this study and this contributed to the inconsistency of findings to previous study. With greater of knee flexion ROM, greater contact time was observed statistically and this matches the findings of Chan et al. (2012). Yet, findings in this study are clinically insignificant as 0.01s is relatively indistinguishable to the rapid movement in running.

GRF and maximum loading rate are statistically insignificant with the presence of medial arch support. This can be explained by the adaptation mechanisms of runners. Nachbauer and Nigg (1992) evaluated the effect of arch height on GRF and no significant effect was found. As such, arch support might not affect GRF in spite of its influences on arch height. Additionally, previous research suggests that maximum loading rate is mainly affected by the stiffness of insoles and athletes ran with harder insoles had a higher loading rate (Perry et al., 2017). As softness of insoles was consistent, significant difference was not found in this study.

Maximum eversion angle and dorsiflexion at initial contact are closely related to pronation, which is considered as the etiologic factor of RRI. Additionally, contact time and knee flexion range of motion are believed to be affected by fatigue and lead to overuse injuries in runners. Regarding the findings obtained, biomechanical parameters are observed to be clinically insignificant on the difference of configurations of insoles. As such, these findings suggest the influence of medial arch support insoles on biomechanical parameters are similar to the flat insoles.

5.2.3 Colors

Colors were found to have insignificant effect on all tested parameters. In this study, three colors were selected for the investigation. Although these colors were commonly tested in the previous study, the influence of other colors cannot be represented and insignificant effect might be due to the limited testing colors. As biomechanical parameters were compared among different colors, it could only be self-adjusted by the subjects upon the visual stimulation of the testing colors. With respect to previous studies, colors mainly influenced the psychology on combat sports because athletes are easily affected by the aggressiveness and superiority that induced by colors (Hill & Barton, 2005). However, running is different from combat sports and less likely to be affected by color psychology. Besides, insignificant effect among colors can also be explained by the exclusion of colors preference. Biomechanical alteration is influenced psychologically by color preference. As preference varied among subjects, changes of biomechanics in testing colors were different and thus, the trend of color preference was not observed from the findings. Findings of this study are also supported by Krenn (2014) and Lam et al. (2017) as it showed that colors alter the perception instead of biomechanical parameters, whereas only kinetics and kinematics data were collected and investigated in this study. Additionally, the visual stimulation site was relatively small when compared to previous studies. Research with significant difference among colors were mainly conducted on sports shoes and attires as runners were stimulated visually throughout the experiment. Although colors of insoles were shown and reminded verbally prior to each trial, participants were unable to access to the stimulation site visually in this study. As such, the psychological influence of colors was limited when compared to previous research and thus, insignificant effect was found in colors to different parameters (Rowe et al., 2005).

5.3 Limitations and further study

5.3.1 Limited sample size

Fourteen subjects were recruited in this study. As the sample size is small, results were easily affected by the variations of data and unable to reflect the influence of different conditions on the population trends completely. Therefore, larger sample size should be used when time is allowed.

5.3.2 Off-the-shelf insoles was used

As the configuration of MLA varies between each subject, the contour of the prefabricated insoles may different from the arch of subjects and it cannot support the medial arch accurately. To eliminate the errors in prefabricated inserts, custom-fitted foot orthoses should be supplied.

5.3.3 Only immediate effect was studied

As data were collected once the subjects stabilized on the treadmill and thus, only the immediate effect of the design of insoles and inclinations could be observed. The changes in biomechanics might be varied in prolonged running and fatigue. Therefore, the evaluation of the influence of insoles on different running duration could be conducted.

5.3.4 Foot strike were not considered

Runners ran on the treadmill without the restriction of foot strike in this study. Although it was observed that most runners performed rearfoot strike in the study, foot strike pattern contributes to the changes of biomechanics. Hence, it should be carefully monitored in future studies.

5.4 Further studies

Previous findings suggest biomechanical changes among colors with sportswear, which have a larger stimulation site when compared with insoles. As difference were not found among the colors of insoles, the contribution of visual stimulation area should be considered. Further studies can investigate the relationship between visual stimulation area and the influence of colors. Additionally, color preference and perceived parameters of the subjects should also be considered in the future as to understand how colors psychology affect perception and biomechanical parameters. The biomechanical changes of the preferred speed could also be tested in further studies as to examine the influence of set and preferred speed on the parameters that related to perception. Further studies could also include foot orthoses of other designs as medial arch support did not have the clinically significant difference in this study and shoes inserts with different characteristics might help to reduce the risk of injury and provide more insoles selections for runners. With the investigation of the further studies, the effect of different designs of insoles and colors on running could be understood more thoroughly.

Chapter 6. Conclusion

Various biomechanical parameters include GRF, maximum loading rate, contact time, vertical oscillation, kinematics of knee and ankle joint between different designs of insoles, as well as different inclinations, were compared. Findings implicated that colors of insoles and medial arch support insoles did not influence the biomechanics of runners. Since the above parameters are related to RRI, the results of this study can give references for design of insole to prevent injury. In addition, results also showed that GRF, maximum loading rate and vertical oscillation decreased with the increase of inclinations. These parameters appear to be related to running injuries. With the reduction of the magnitude of these parameters, RRI-related parameters are improved when compared to level running.

Chapter 7. Reference

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Appendix
Appendix I: Consent Form



Li Ning Sports Science Research Center, Beijing, China

Studies on Human Subjects
- Informed Consent and Exclusion of Liability
运动生物力学研究—受试者知情同意书

Study Title: Biomechanical gait evaluation of the effects of colored medial arch support on running on inclined surface

研究题目： 鞋垫设计对不同坡道跑步的运动学和动力学的影响

Study Head: LokYee Pak

研究负责人： 白乐怡

Phone/手机： +852 65800725

E-Mail/邮箱： pak.louisse@gmail.com

受试者资料：

姓名：_____

电话：_____

地址：_____

邮箱：_____

Declaration:

声明：

I have been informed in detail about all measures and procedures of the above-mentioned study by the study head or related coworkers.

我已从负责人或相关工作人员处获悉此次研究的具体内容和方法。

I would like to volunteer as a subject in the study mentioned above.

我自愿成为此次研究的受试者。

I understand that I have the right to withdraw my consent to take part in the study at any time during the study procedures without facing any consequences whatsoever.

我有权在任何时间退出此次研究，并且对此带来后果不承担责任。

I understand that in case of occurrence of any resulting injuries or damages while participating in the above mentioned study I am not entitled to raise any liability claims.

我理解在此次研究中如果出现任何伤害或损伤，我将无权提出索赔。

I agree that any of my personal data provide during the participation in this study is treated confidentially and for scientific and administrative purposes only.

我同意为此次研究提供真实的个人资料，该资料仅用于此次研究需要并被保密。

I declare that I will not share any information related to the study content to third parties without prior authorization.

我承诺不对未经授权的第三方提供任何与此次研究相关的信息。

签名: _____



Li Ning Sports Science Research Center, Beijing, China

資料表

鞋垫设计对不同坡道跑步的运动学和动力学的影响

欢迎您参加由香港理工大学生物医疗工程系本科生白乐怡的研究。

本研究的目的在于通过运动学和动力学来评估及分析不同鞋垫设计对坡道跑步的影响。您将会被安排李宁运动科学研究中心穿着不同设计的鞋垫进行跑步。整个实验过程将会在实验仪器的录像下进行。在实验过程中，您需要跟从工作人员的指示，并在完成分段实验后休息及更换鞋垫。李宁运动科学研究中心所得出的数据将会被用作研究鞋垫设计与跑步表现之间的关系。希望研究结果能够指出鞋垫设计和跑步表现的关系，以改良目前的鞋垫设计，提高运动员的比赛表现。

您将需要在跑步机上进行多次不同坡道的跑步，但测试不应该导致任何不适。所有与您相关的信息将严格保密，而研究人员亦只会透过代号进行识别。

您有权在测量之前或期间中退出研究，及不受任何负上任何形式的惩罚。整个研究需时大概2个小时。

如欲查阅有关本研究的资料或对本研究有任何投诉或疑问，请联络白乐怡小姐 (电话：+85265800725 / 电邮：pak.louisse@gmail.com) 。

感谢您有兴趣参与本研究。

白乐怡小姐
首席研究员

Appendix IIb: Information Sheet (English Version)



Li Ning Sports Science Research Center, Beijing, China

Information Sheet

Biomechanical gait evaluation of the effects of colored medial arch support on running on inclined surface

You are invited to participate in a study conducted by Pak Lok Yee, who is an undergraduate student of the Department of Biomedical Engineering in The Hong Kong Polytechnic University.

The purpose of this study was to evaluate and analyze the impact of different insole designs on running treadmill with kinematics and kinetics. You will be arranged Li Ning Sports Science Center wearing different designs of insoles to perform running. The whole experiment will be carried out under the video of the experimental apparatus. During the experiment, you will need to follow the staff instructions and exchange different designs of insoles after completing the staging experiment. Data from the personal performance assessment form and data from Li Ning Sports Science Research Center will be used to study the relationship between insole design and running performance. I hope the results of the study can indicate the relationship between insole design and running performance to improve the current insole design and improve the performance of athletes.

You will need to run many different ramps on your treadmill, but the test should not cause any discomfort. All information about you is strictly confidential, and researchers are only identified by code.

You have every right to withdraw from the study before or during the measurement without penalty of any kind. The entire study will take about 2 hours.

If you would like to obtain more information about this study, please contact Pak Lok Yee (tel. no.: 65800725 / email: pak.louisse@gmail.com).

Thank you for your interest in participating in this study.

Miss Pak Lok Yee

Principal Investigator

参考编号:

实验前问卷调查

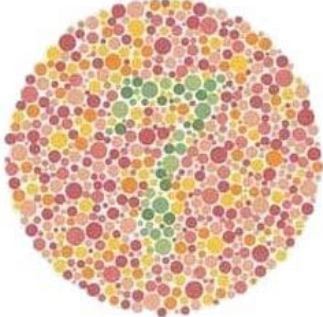
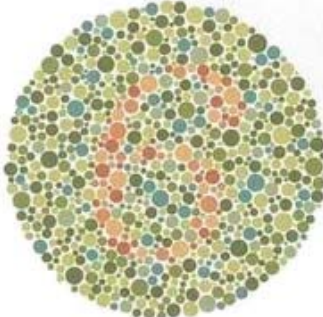
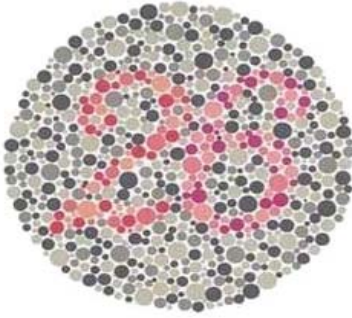
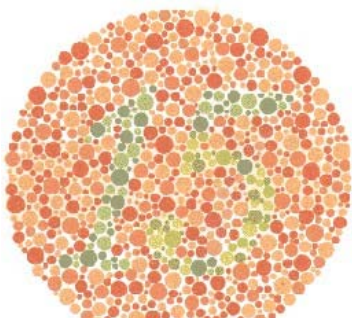
第一部分 - 个人资料

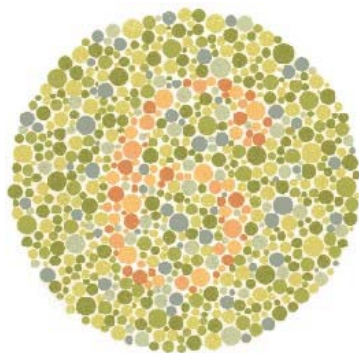
性别: _____
年龄: _____
身高: _____
体重: _____
惯用脚: _____

第二部分 - 鞋碼、扁平足測量

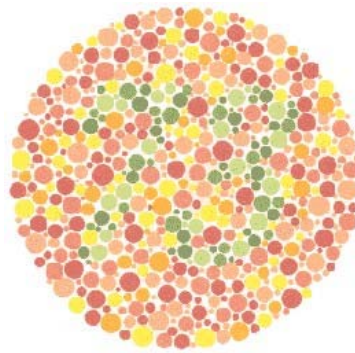
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扁平足等級: _____

第三部分 - 色盲測試

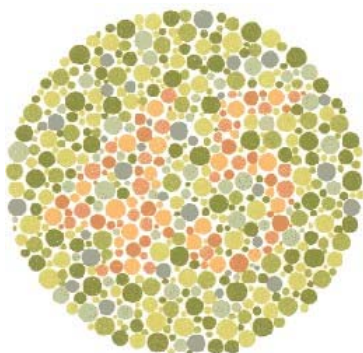
 答案: _____	 答案: _____
 答案: _____	 答案: _____



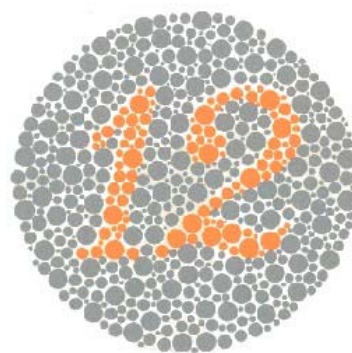
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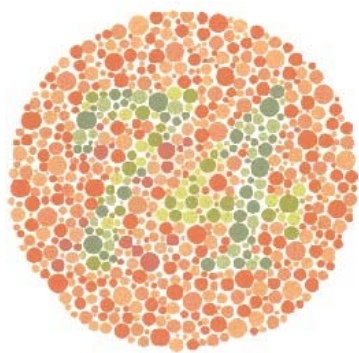
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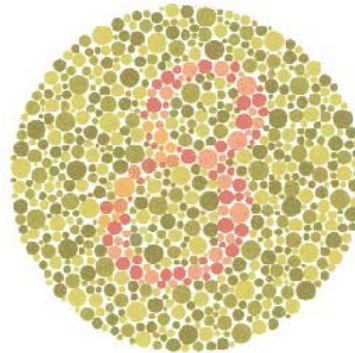
答案: _____



答案: _____



答案: _____



答案: _____

Appendix IIIb: Personal information & color blindness test (English Version)

Reference No.:

Pre-experimental Questionnaire

Personal information

Gender: _____

Age: _____

Height: _____

Weight: _____

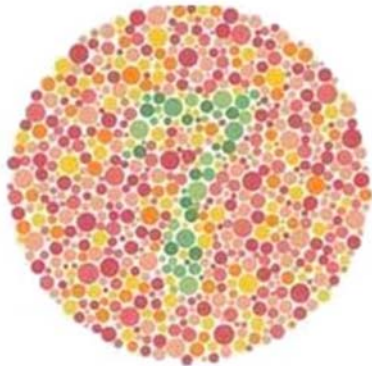
Dominance Foot: _____

Shoe size, flat foot measurement

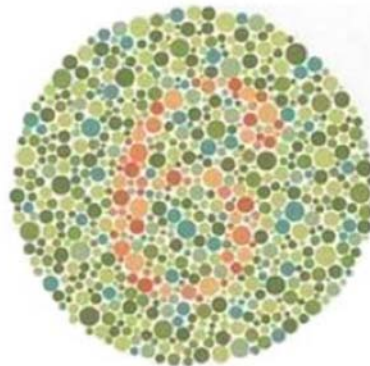
Shoe size: (right) _____ (left) _____

Flatfoot Level: _____

Color blindness test



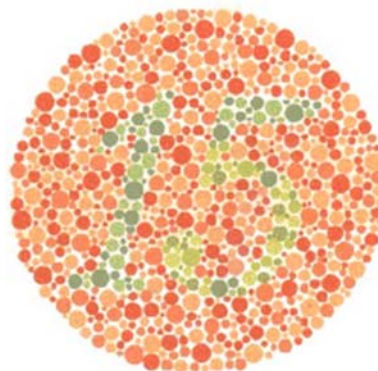
Ans : _____



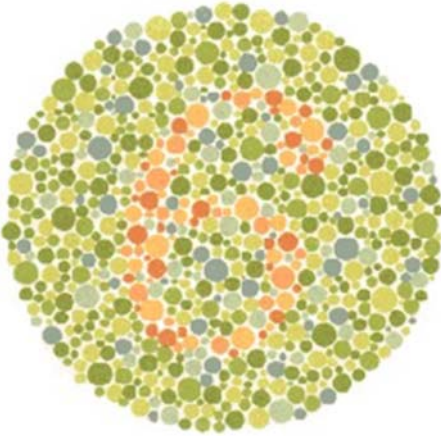
Ans : _____



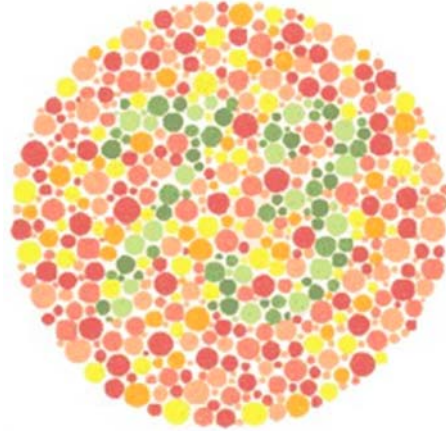
Ans : _____



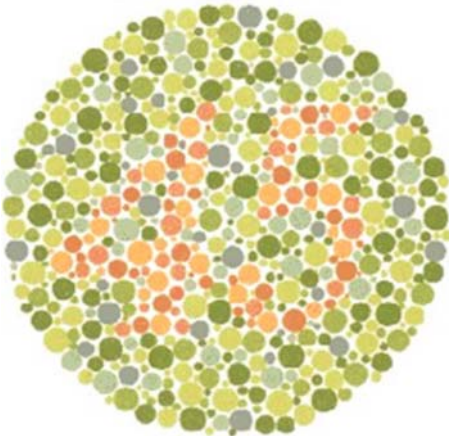
Ans : _____



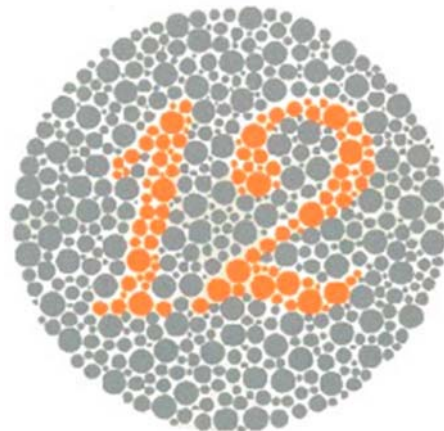
Ans : _____



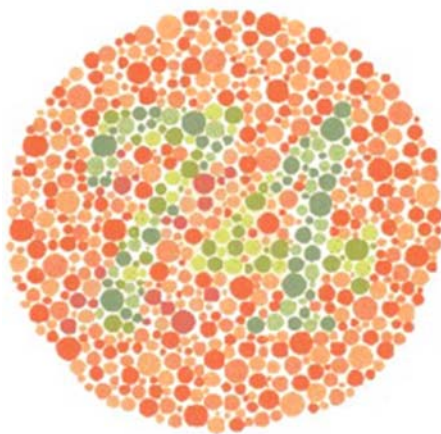
Ans : _____



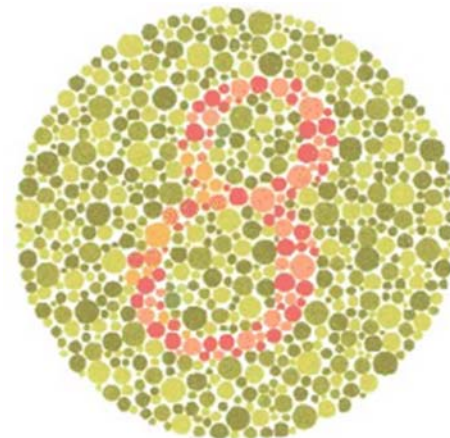
Ans : _____



Ans : _____



Ans : _____



Ans : _____

参考编号:

实验前问卷调查

第四部分 - 運動背景

1. 在过去一星期, 你平均使用多少时间于跑步训练或比赛上?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7天

2. 在过去六个月, 你有没有曾运动受伤?

☐ 有,

受伤的部位在哪?

☐ 上肢, 请列明: _____

☐ 下肢, 请列明: _____

☐ 没有

—完—

**Appendix IVb: Questionnaire on running background and injury history
(English Version)**

Reference No.:

Pre-experimental Questionnaire

Running background and injury history

1. In the last week, how many days have you spent on running training or competition?
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

2. In the past 6 months, did you have any running injuries?

☐ Yes,

Where was the injuries ?

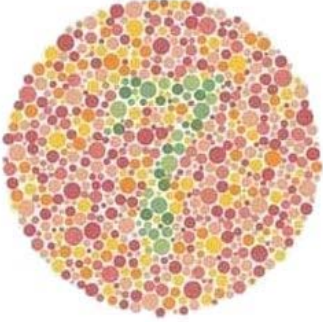
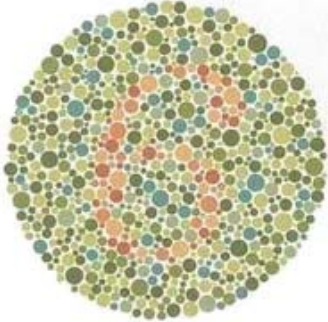
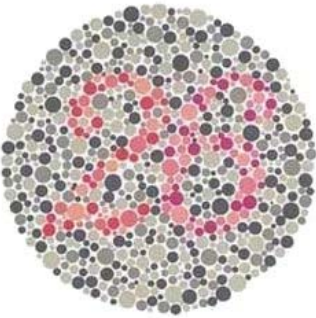
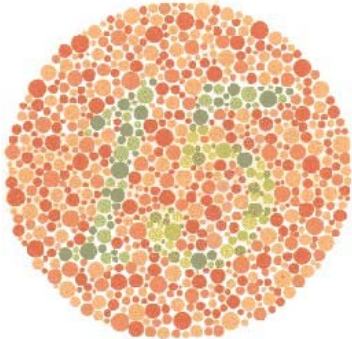
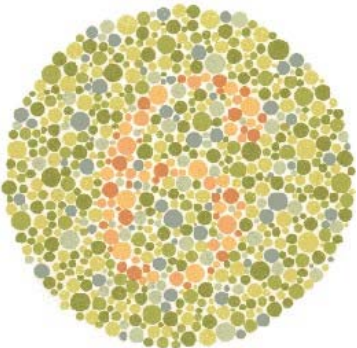
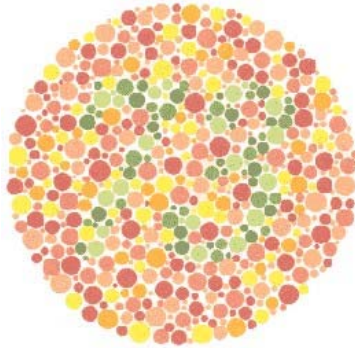
☐ Upper limb, please state : _____

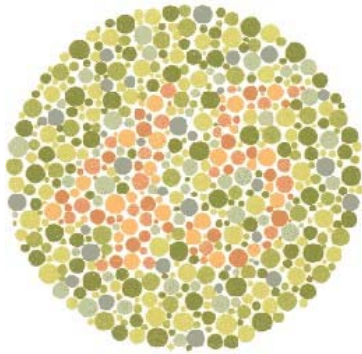
☐ Lower limb, please state : _____

☐ No

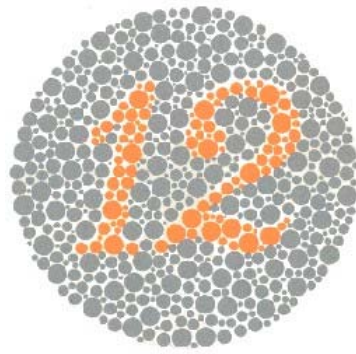
– End –
Thank you

Appendix V: Ishihara color blindness test explanation

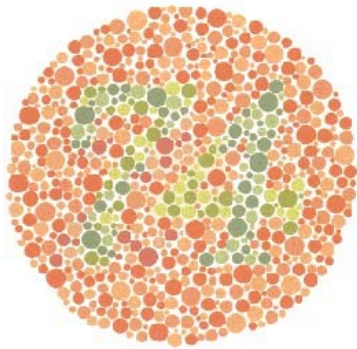
 Answer is 7. For general colorblindness classification	 Answer is 6. For general colorblindness classification
 Answer is 26. For red colorblindness will see 6 For green colorblindness will see 2	 Answer is 15. For red-green colorblindness classification
 Answer is 6. For general colorblindness classification	 Answer is 73. For general colorblindness classification



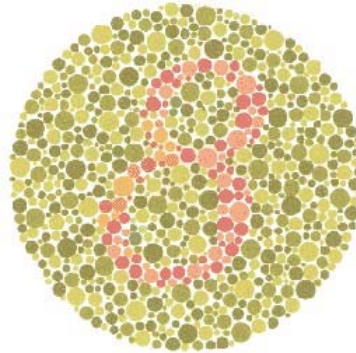
Answer is 45.
For normal color vision classification



Answer is 12.
For normal color vision classification



Answer is 74.
For red-green colorblindness classification



The number pictured is 8.
For normal color vision classification

(Retrieved from: <https://colormax.org/color-blind-test/>)

程序表

1. 量度体重、高度	1分钟
2. 量度运动鞋尺寸、扁平足测试	5分钟
3. 色盲测试、运动受伤调查问卷	5分钟
4. 阅读研究介绍及签署同意书	3分钟
5. 更换衣物及运动鞋	5分钟
6. 热身跑步	2分钟
7. 反光标记	10分钟
8. 开始实验	60分钟
穿着四对不同设计的鞋垫，进行三个不同坡度的跑步	
8.1. 换上放有测试鞋垫的球鞋	
8.2. 系统校对	
8.3. 跑步测试	
8.4. 重复8.1至8.3三次（四对不同设计的鞋垫）	
8.5. 休息及更换放有不同鞋垫的球鞋跑步	
8.6. 重复8.1至8.5二次（三个不同坡度）	
9. 完成实验	

Appendix VIb: Brief procedure (English Version)

Procedure

1. Measurement of height and weight	1 min
2. Measurement of shoes size and flat feet test	5 mins
3. Color blindness test and questionnaire on injury history	5 mins
4. Information sheet and consent form	3 mins
5. Changing clothes and running shoes	5 mins
6. Warm ups	2 mins
7. Marker placement	10 mins
8. Experiment	60 mins
Running in 3 different slopes with 4 different pairs of insoles	
8.1. Changing the tested insoles	
8.2. Static alignment	
8.3 Running trial	
8.4. Repeat 8.1 to 8.3 for 3 times (4 different pairs of insoles)	
8.5. Rest	
8.6. Repeat 8.1 to 8.5 for 2 times (3 different slopes)	
9. Experiment completed	

Appendix VII: Marker Placement





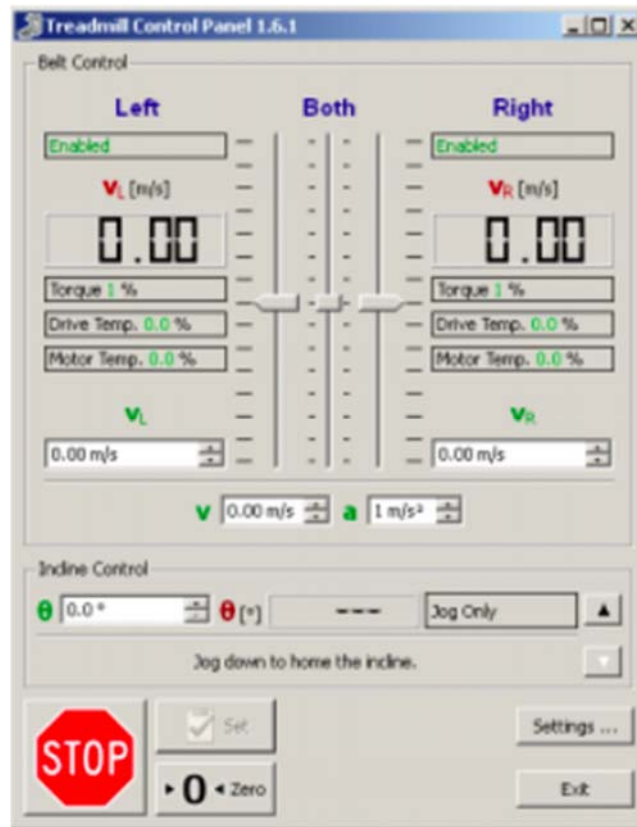


Marker Plate for shank (left) and thigh (right)

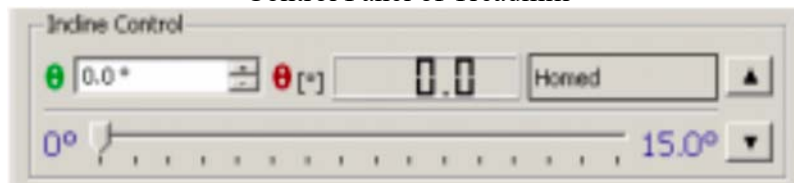


Straps for marker plate (left) and 12 markers which stick on bony prominence (right)

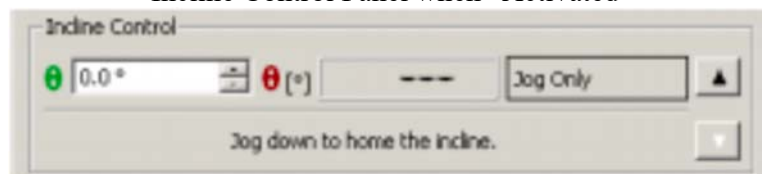
Appendix VIII: Control panel of treadmill



Control Panel of Treadmill



Incline Control Panel when “Activated”



Incline Control Panel when “Inactivated”

Appendix IX: Demographic data for subjects

	Mean	SD
Age (year)	21.21	1.97
Height (m)	179.11	3.10
Weight (kg)	75.20	3.51

Subject	Sex	Age (yrs)	Height (m)	Weight (kg)
1	M	19	1.75	78.2
2	M	20	1.77	66.8
3	M	19	1.81	79.4
4	M	25	1.80	75.9
5	M	23	1.77	74.9
6	M	20	1.81	70.2
7	M	20	1.78	77.9
8	M	22	1.80	76.6
9	M	19	1.77	75.7
10	M	22	1.73	72.3
11	M	25	1.82	75.2
12	M	21	1.82	72.9
13	M	22	1.85	80.1
14	M	20	1.82	76.7

Appendix X: Biomechanical parameters under different inclinations

Parameters	Slopes						
	0°		3°		6°		<i>P-value</i>
	Mean	SD	Mean	SD	Mean	SD	
GRF (BW)	2.36*	0.072	2.30*	0.067	2.28*	0.061	0.000
Maximum loading rate (BW/s)	112*	6.27	91.2*	5.02	77.7*	4.86	0.000
Vertical oscillation (m)	0.08*	0.004	0.08*	0.004	0.07*	0.004	0.000
Contact time (s)	0.25*	0.003	0.26*	0.003	0.26*	0.004	0.001
Stride length (m)	2.09	0.037	2.08	0.041	2.06	0.045	0.052
Stride frequency (Hz)	1.44*	0.026	1.45*	0.030	1.47*	0.033	0.049
Ankle Angle in sagittal plane at initial contact (deg)	2.40*	1.17	5.97*	0.958	9.01*	1.05	0.000
Ankle angle in sagittal plane at toe off (deg)	-12.7	1.712	-13.8	1.091	-14.1	1.281	0.402
Inversion-eversion ROM (deg)	10.3*	0.730	9.00*	0.551	8.27*	0.505	0.001
Maximum eversion angle (deg) [#]	-11.5	0.342	-11.7	0.167	-11.1	0.730	0.624
Knee angle in sagittal plane at initial contact (deg)	-13.9	1.01	-19.0	1.43	-26.1	1.65	0.000
Knee angle in sagittal plane at toe off (deg)	-18.5	1.21	-14.8	3.07	-17.4	1.53	0.362
Knee flexion ROM (deg)	-24.3	1.95	-22.4	2.25	-24.6	2.63	0.067
Maximum knee flexion (deg)	-39.3	1.14	-37.5	3.42	-43.3	0.959	0.079

[#]. Interaction is significant at .05 level

*. Mean difference is significant at .05 level

Appendix XI: Biomechanical parameters under present and absent of medial arch support

Medial arch support					
Parameters	Present		Absent		
	Mean	SD	Mean	SD	<i>P-value</i>
GRF (BW)	2.32	0.065	2.30	0.067	0.344
Maximum loading rate (BW/s)	93.2	4.73	93.0	4.30	0.955
Vertical oscillation (m)	0.08	0.004	0.07	0.004	0.073
Contact time (s)	0.26*	0.003	0.25*	0.003	0.001
Stride length (m)	2.08	0.042	2.07	0.039	0.809
Stride frequency (Hz)	1.46	0.03	1.46	0.028	0.932
Ankle Angle in sagittal plane at initial contact (deg)	6.27*	1.10	5.31*	0.93	0.014
Ankle angle in sagittal plane at toe off (deg) [#]	-	-	-	-	-
Inversion-eversion ROM (deg)	9.32	0.633	9.08	0.455	0.342
Maximum eversion angle (deg) [#]	-	-	-	-	-
Knee angle in sagittal plane at initial contact (deg)	-19.4	1.23	-19.8	1.23	0.201
Knee angle in sagittal plane at toe off (deg)	-17.8	1.28	-16.0	2.27	0.443
Knee flexion ROM (deg)	-24.3*	2.28	-23.2*	2.16	0.000
Maximum knee flexion (deg)	-41.5	0.969	-38.6	2.53	0.185

[#]. Interaction is significant at .05 level

*. Mean difference is significant at .05 level

Appendix XII: Biomechanical parameters under different colors of insoles

Parameters	Colors						
	Red		Blue		White		P-value
	Mean	SD	Mean	SD	Mean	SD	
GRF (BW)	2.32	0.066	2.32	0.065	2.32	0.065	0.862
Maximum loading rate (BW/s)	93.8	4.85	93.3	4.80	93.2	4.73	0.439
Vertical oscillation (m)	0.076	0.004	0.075	0.004	0.076	0.004	0.801
Contact time (s)	0.26	0.003	0.26	0.003	0.26	0.003	0.299
Stride length (m)	2.07	0.042	2.05	0.043	2.08	0.039	0.206
Stride frequency (Hz) [#]	-	-	-	-	-	-	-
Ankle Angle in sagittal plane at initial contact (deg)	6.71	1.29	5.90	0.800	6.27	1.10	0.739
Ankle angle in sagittal plane at toe off (deg)	-11.9	1.69	-14.1	1.21	-13.6	1.15	0.142
Inversion-eversion ROM (deg)	9.56	0.627	9.27	0.541	9.32	0.633	0.604
Maximum eversion angle (deg)	-12.1	0.555	-11.2	0.573	-11.8	0.482	0.795
Knee angle in sagittal plane at initial contact (deg)	-18.6	1.77	-19.2	1.31	-19.4	1.23	0.511
Knee angle in sagittal plane at toe off (deg)	-17.5	1.56	-18.1	1.21	-17.8	1.28	0.749
Knee flexion ROM (deg)	-26.4	1.02	-24.6	1.49	-27.0	1.58	0.571
Maximum knee flexion (deg)	-40.2	1.70	-41.4	0.965	-41.5	0.969	0.354

[#]. Interaction is significant at .05 level

*. Mean difference is significant at .05 level

Appendix XIII: Parameters in one-way ANOVA with repeated measures

1. Maximum eversion angle (deg) for the medial arch support against slopes

Medial Arch Support	0°		3°		6°		<i>P-value</i>
	Mean	SD	Mean	SD	Mean	SD	
Present	-12.3*	0.721	-10.5*	0.584	-12.4*	0.557	0.001
Absent	-11.2	0.763	-11.0	0.430	-11.5	0.553	0.479

*. Mean difference is significant at .05 level

Medial Arch Support	<i>Present</i>		<i>Absent</i>		<i>P-value</i>
	Mean	SD	Mean	SD	
0°	-12.3*	2.70	-11.2*	2.85	0.040
3°	-10.5	2.18	-11.0	1.61	0.181
6°	-12.4*	2.08	-11.5*	2.07	0.000

*. Mean difference is significant at .05 level

2. Ankle angle in sagittal plane at toe off (deg) for the medial arch support against slopes

Medial Arch Support	0°		3°		6°		P-value
	Mean	SD	Mean [#]	SD [#]	Mean [#]	SD [#]	
Present	-13.1	1.18	-14.4	1.20	-13.2	1.42	0.347
Absent	-14.8	5.49	-13.5	4.60	-14.8	5.40	0.24

*. Mean difference is significant at .05 level

Medial Arch Support					
	<i>Present</i>		<i>Absent</i>		<i>P-value</i>
	Mean	SD	Mean	SD	
0°	-13.1	1.18	-14.8	1.47	0.057
3°	-14.4	4.46	-13.5	4.60	0.134
6°	-13.2	5.34	-14.8	5.40	0.056

*. Mean difference is significant at .05 level

3. Stride frequency (Hz) with different colors of insoles against slopes

Colors	Red		Blue		White		<i>P-value</i>
	Mean	SD	Mean	SD	Mean	SD	
0°	1.44	0.03	1.43	0.03	1.43	0.03	0.917
3°	1.46	0.12	1.46	0.12	1.46	0.11	0.921
6°	1.48	0.035	1.48	0.034	1.47	0.033	0.432

*. Mean difference is significant at .05 level

Colors	0°		3°		6°		<i>P-value</i>
	Mean	SD	Mean	SD	Mean	SD	
Red	1.44	0.029	1.46	0.031	1.48	0.035	0.087
Blue	1.43	0.029	1.46	0.031	1.48	0.034	0.008
White	1.43	0.026	1.46	0.028	1.47	0.033	0.01

*. Mean difference is significant at .05 level