ISSN: 2710-0723

Footwear Design and Biomechanics Evaluation for Clinical Nurses

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Abstract

Epidemiological investigations have shown a higher prevalence of work-related musculoskeletal disorders, (WRMDs) among nursing professionals. More than most other occupational groups. Most nursing activities require long periods of standing and walking. These job requirements can cause WRMDs problems in the lower limbs, and there are few footwear products available specifically for use by clinical nurses. Therefore, improving the current clinical nurse shoes and improving the wearing comfort of clinical nurse shoes are the necessary conditions to reduce the lower limb discomfort of clinical nurses. The purpose of this study is :(1) to test and obtain the foot morphology and walking gait characteristics of nurses in standing state by using human foot scanning and sports biomechanics technology, and to design comfortable clinical nursing footwear products suitable for nurses through shoe last optimization and application of environmentally friendly materials. (2) Sports biomechanical testing technology was used to test and compare the developed clinical care shoes with other shoes in the market, and the biomechanical characteristics of participants wearing different shoes were measured and compared to verify the design effect of clinical care shoes and improve it. This research method is divided into three stages. First, field observations and exercise biomechanics tests of the participants were performed, and data acquisition included plantar pressure characteristics, a three-dimensional foot model, foot surface temperature distribution, walking speed, and proportions of walking, standing, and sitting. Secondly, the clinical nursing shoes were designed based on the test results and the sample shoes were made. Finally, the function of professional nursing was evaluated through the exercise biomechanical testing technique. Measurements included lower limb joint range of motion (ROM), foot Pressure, ground reaction force (GRF), and subjective discomfort ratings for the lower body and feet. To summarize the findings of this study, comfortable clinical care shoes should emphasize arch support at the sole, use three-dimensional vertical insoles, and design heel height below 5 cm to significantly reduce plantar pressure distribution and ground impact, increase ankle flexibility, and recommend the use of pressure socks to reduce the risk of varicose veins in the lower extremities.

Keywords

Footwear Design; Biomechanics; Foot Scanning; Clinical Nursing; Nurse.

1. Introduction

Although work-related musculoskeletal disorders are not included in the Classification and Catalogue of Occupational diseases, they are highly correlated with occupational activities and have a wide range of hazards to the health of occupational populations. With the rapid development of economy and society, occupational health hazards have changed from traditional occupational hazards to new occupational hazards. In the Health China Occupational Health Protection action, it is clearly pointed out that to prevent and control the occurrence of excessive fatigue and work-related musculoskeletal system diseases, in addition, the prevention of work-related musculoskeletal disorders was implemented in three occupational

ISSN: 2710-0723

groups, including those who work with standing posture, such as teachers, traffic policemen, doctors and nurses, and those who work with fixed posture for a long time, such as drivers.

Work-related musculoskeletal disorders (WRMDs) are a common occupational morbidity, including injuries and symptoms of various parts of the musculoskeletal system. Work-related musculoskeletal disorders (WMSDs) are musculoskeletal disorders caused by or mainly caused by work, which have a high prevalence and heavy disease burden, and have become a global problem. The most common is occupational lower back disorders, followed by neck and shoulder disorders. The most common sites of WRMDs include lower back, neck, shoulders, upper back, hips/thighs, knees, elbows, wrists/hands, ankles/feet, etc. Studies have shown that nearly 80% of adults will suffer from lower back pain (LBP) in their lifetime, 4%-5% of people have an acute attack of LBP every year, and many of the occurrence of low back pain is related to occupational factors. WRMDs seriously threatens the health, work ability and life quality of workers. It is the main reason for the decline of the occupational labor force of 20-55 years old. In recent decades, the problem of occupation-related chronic musculoskeletal disorders has become increasingly prominent, affecting more than half of the occupational population, and foreign reports of the disease occupy the second place in the occurrence of occupational diseases, second only to occupational skin diseases. The nursing profession is more likely to suffer from occupational musculoskeletal disorders, and epidemiological surveys of nurses have shown that prolonged upright posture may lead to health hazards such as low back problems, plantar fasciitis, tendinitis, cumulative muscle fatigue, and varicose veins. The prevalence rate of WMSDs in nursing staff is much higher than that in the general population, which may be due to the occupational factors in clinical nursing work, but the initial symptoms are not obvious and easy to be ignored by nursing staff and managers. Studies have shown that nurses are at high risk of low back pain, and the risk of nurses and care workers suffering from low back pain among professional women is 2.5 times that of other professions. In the next 10 to 15 years, the third period of high incidence of occupational diseases may appear in China, and nursing staff, professional managers and teachers have become the three groups with the greatest occupational pressure. The severity, site involved, risk factors and ergonomic load of WMSDs in nursing industry need to be studied.

At present, in order to alleviate the lower limb discomfort caused by MSD, the means that have been taken include physical massage, as well as some treatment and recovery products, such as insoles, corrective shoes, etc. Considering the characteristics of the nursing profession, it is necessary to provide professional shoes for clinical nurses to alleviate the lower limb fatigue caused by work.

From a clinical point of view, the design of footwear products has a huge impact on human health. The outer sole design of footwear products can effectively block the sole of the foot from ground damage, the middle sole of the shoe can effectively buffer the impact force of the bottom surface, and the design of the inner sole of the shoe can support the arch of the foot and reduce the occurrence of plantar fasciitis and flat foot fatigue. In terms of shoe-making materials, the inner sole and mid-sole flexible materials can effectively relieve the pain of standing for a long time on the back, legs and feet of the human body, and the softness and breathability of the upper surface materials can realize the dry and comfortable shoe cavity and avoid the growth of foot bacteria. The design of the last shape ultimately determines the shape of the shoe, and whether the shape of the shoe is consistent with the shape of the wearer's foot determines whether the shoe fits the foot, and the shoes that do not fit the foot are bound to bring more damage. In addition, heel height also affects foot pressure distribution and vertical impact force. It has been reported that compared with flat shoes, high heels have obvious differences in the distribution of sole pressure and the maximum impact of the sole.

In addition, standing for long periods of time causes limited circulation in the lower legs, such as varicose veins. Pressure socks that relieve varicose veins are known to promote venous

ISSN: 2710-0723

blood return, and various forms of compression socks are effective in relieving ankle and calf swelling and reducing lower limb discomfort. In view of the current research on the lower limb health of nurses mainly focuses on pressure socks, and limited research only evaluates the wear performance of footwear products for clinical nurses. This study first designed clinical care footwear products based on the test results of human foot type and sports biomechanics, and evaluated the performance of footwear products, which is significantly innovative compared with previous studies.

The purpose of this study is twofold :(1) to design and develop two types of nursing shoes according to the foot morphological characteristics of the nursing profession and the results of exercise biomechanical test; (2) to evaluate the wearing effect of the design and development of nursing shoes through biomechanical measurement and subjective lower limb discomfort reaction, and to verify the performance of the project development products. The nurse shoes designed and developed in this study can provide useful reference for nursing professionals to reduce lower limb MSD problems and improve job satisfaction and work efficiency.

2. Methods

The study was divided into two phases; First, the test equipment was used to collect foot data, exercise biomechanics test and field observation of working state of clinical nurses in a hospital, collect work-related data, and design and develop two types of footwear products worn by nurses. Then the experimental evaluation of two types of nurse shoes under laboratory conditions was carried out to verify the performance of the design and development of nurse shoes.

2.1. Stage One: Field Test

In this stage, the test and observation method are adopted to design and develop sports shoes specially used for clinical nurses according to the test results. This stage mainly tests the foot type, plantar pressure distribution, ground reaction force and foot surface temperature of the nursing profession. The test process was divided into pre-work and after 4 hours, and the test data were recorded respectively. The test subjects selected clinical nurses in the hospital, 4 were named internal medicine, 4 were named surgery. Their professional duties include taking patients' vital signs, administering drugs and injections, collecting or assisting with special examinations, and handling patient requests. These nurses work mostly standing and walking during normal shifts, and only choose to sit when recording. During work, nurses walk, stand, and sit in a ratio of 1.7:1.7:1.

2.2. Stage Two: Nurse Shoe Design

Two types of nurses' shoes designed by ourselves were adopted as the research objective in this study. The design of the two types of nurses' shoes was mainly based on the collected foot type data, plantar pressure distribution data and foot surface temperature distribution data of nurses. Among them, foot type data was used to design and develop shoe last to meet the needs of clinical nurses' shoes. The plantar pressure distribution is mainly used for the design of sole structure and the selection of materials. The data of foot surface temperature is mainly used to evaluate the change of foot temperature from wearing shoes for a long time, as well as the selection of heat dissipation materials for the upper surface and the design of breathable structure. The two types of nurse shoes developed in this design are designed according to the functional requirements of the following two types: Middle heel 2.5cm, using synthetic leather upper, part of the design has air holes; High heels 5cm, sole material is rubber, upper surface is natural leather.

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2.3. Stage Three: Experimental Evaluations

2.3.1. Participants

Sixteen healthy women were from five hotel service workers, five school students and six hospital nurses. Employed to participate in this study. The mean age was 25.5 years (SD3.15 years), the mean height was 159.6 cm (SD4.12 cm), and the mean weight was 48.4kg (SD3.95 kg). None of the selected participants had lower limb injury, physical disability or discomfort. At the beginning of the experiment, foot anthropometric data were collected for each participant (Table 1).

2.3.2. Experimental Design

A completely random factor design was used in this experiment. In the nurses' footwear assessment, each participant randomly wore three company-developed shoes without any socks. Figure 1 shows the three professional care shoes developed.

Table 1. The anthropometric data of the participants

Participants(n=12)	Average	SD
Age(years)	25.5	3.15
Height(cm)	159.6	4.12
Weight(kg)	48.4	3.95

Figure 1. Shoes for experimental nurses, wearing bare feet

The two footwear products used in the test are made of new shoe lasts designed and developed through the results of foot shape testing. The study used three different shoe sizes, 36, 37 and 38, so that each participant chose the most suitable shoe. Since most participants wore size 36 shoes, the footwear characteristics described in Table 2, including shoe width, shoe weight, sole thickness, sole material, arch support, and upper, were based on size 37 shoes. Sole thickness includes metatarsal zone thickness (MP thickness), which is the vertical distance from the first metatarsal bone to the sole. Heel height is the vertical distance from the heel to the sole of the shoe. The two products are shoes with a 2.5cm heel, and the outsole and midsole material are vinyl acetate (EVA). The shoes with a thickness of 5cm heels are made of rubber material on

ISSN: 2710-0723

the outsole, and the insole insole of both shoes is made of foamed polyurethane and bonded leather material on the surface. The upper material of the two shoes is synthetic leather of different hardness.

All participants wore no socks while wearing the test shoes.

Table 2. The specifications of the two nurse shoes (shoe size 37)

Type	Shoe breadth(cm)[a]	Weight(kg/pair)	Sole					Shoe upper
			Thickness(cm)		Bottom material		Footbed	
			MP[b]	Heel	Outsole	Midsole		
A	9.2	0.54	2.2	2.5	EVA	EVA	PU and leather	Artificial leather
B	9.6	0.61	1.9	5.0	Rubber	Rubber	PU and leather	Artificial leather

[a]The forefoot breadth in the shoe.

[b]MP means the vertical distance from first metatarsal to shoe bottom.

2.3.3. Instruments

1) Motion capture system. A Single camera Motion capture system (Quintic) was used to record the range of motion (ROM) of the knee and ankle joints at a sampling rate of 120 Hz, and the joint Angle data was obtained using image analysis software provided by Quintic. The articular Angle is calculated by connecting the three related marks on the sagittal plane by capturing the image of the unmatched side.

2) Foot pressure measurement system. The foot pressure distribution is measured using a foot pressure measuring device (Footscan system, RSscan1.5m flat panel). Rsccan software was used to collect the foot pressure data at a frequency of 100 frames per second. Foot pressure data were measured in seven areas, including toe (T1), phalanges 2-5 (T3), metatarsal 1 (M1), metatarsal 2-3 (M3), metatarsal 4-5 (M5), arch (V), and heel (H). The average peak pressure in each plantar region was calculated in a series of steps.

3) GRF.GRF is measured by a three-dimensional force measuring table (Hefei Aili) with a sampling rate of 500 Hz. The original force data were analyzed by using the software of Hefei Aili three-dimensional force measuring table. According to the characteristics of vertical GRF, during normal walking, the first maximum vertical force (heel strike) occurs at initial contact, the second maximum vertical force (metatarsal touch), the other lower limb occurs in the pre-swing phase, and the minimum force (foot flat) occurs in the middle stage of standing. During the walk, the vertical impact force in three stages of a gait cycle was recorded, namely heel strike, foot release and metatarsal touch.

4) Infrared thermal imaging test. Use infrared thermal imager (Shanghai JuGe Electronics, MAG62, 640*480, uncooled detector) to shoot the temperature distribution of the barefoot meter.

2.3.4. Experimental Process

In this study, which focused on evaluating the performance of a nurse's shoe designed to simulate clinical nursing work, each participant was asked to perform tasks for 30 consecutive minutes, first walking (10 minutes), then standing (10 minutes) and sitting (10 minutes).

Before the start of the experiment, the participants were first introduced to the purpose and procedure of the experiment, and the two types of shoes were assigned to each participant in

ISSN: 2710-0723

random order. Four reflex markers were placed at the hip, knee, ankle and 5th metatarsal bone for motion capture. At the start of the experiment, participants walked for 10 minutes on a treadmill at a speed of 2.0 km/h. After walking on a treadmill, the participants continued to walk on a 10m path for five minutes. Experimental measurements included ankle and knee ROM, foot pressure distribution, and gait GRF. The participants then remained in a standing position for 10 minutes. After the standing task, participants were allowed to sit down and rest for 10 minutes.2.3.5. Statistical analysis. Single factor analysis of variance (ANOVA) was used to compare the difference of sports biomechanical data.

3. Results and Discussions

3.1. The Shoe Effects

Table 3 give the results of the analysis of variance for the two nursing shoes. In lower limb joint ROM, wearing the two types of shoes did not cause a significant difference in knee and ankle movement, which may be due to the small difference (2.5 cm) in heel height between the two types of nursing shoes in this study. In the influence of shoes on foot pressure distribution, there were significant differences in the toe, phalanx, first metatarsal bone, second to third metatarsal bone, fourth to fifth metatarsal bone, arch area and heel area. The plantar pressure of the two products is significantly different. The A (2.5cm heel height) takes the plantar pressure less and can fully and evenly distribute the pressure of the toes and the metatarsal area. The design of the lower heel is better for the support effect of the assembly, which helps to distribute the arch pressure and reduce the fatigue of the calf muscles.

Table 3. The ANOVA results for two nurse shoes (n=16)

Measurements	Df	F-ratio	Significance
Range of motion(deg)			
Knee	15		0.55
Ankle	15		0.39
Foot pressure(N/cm^2)			
Toe	15		0.03*
2nd-5th phalanges	15		0.00*
1st metatarsals	15		0.00*
2nd-3rd phalanges	15		0.00*
4-5th metatarsal	15		0.00*
Arch	15		0.04*
Heel	15		0.00*
Ground reaction force(N)			
Heel strike	15		0.01
Foot flat	15		0.37
Toe off	15		0.21

*Significance level at P<0.05.

ISSN: 2710-0723

In the GRF test, the vertical impact force showed a significant difference when the sole of the foot fully touched the ground and when the metatarsal bone left the base. When the sole of the foot fully touches the ground, the vertical impact force produced by wearing A shoe is lower than that of wearing B shoe. In terms of foot pressure distribution and GRF, wearing A shoes has a positive effect on reducing plantar pressure and vertical impact force in foot plane stage. This may be because the outsole thickness of A shoes is not much different from that of B shoes, but the heel height is low. In addition, the outsole of the heel area mainly acts as a buffer to absorb the vertical impact force during walking. The damping effect of the heel area depends on the thickness and material type of the outsole. The thickness of outsole in heel area A and B is 9.2cm and 9.6cm respectively. The outsole materials of shoes A and B are EVA and rubber respectively. Shoes A with a 2.5cm EVA outsole produce lower heel pressure than shoes B with a rubber sole and a 5cm heel height. Therefore, when choosing care shoes, shock absorbing materials and heel height must be considered at the same time.

4. Conclusion

This study evaluated two self-designed nursing shoes. Measurements included range of motion in the ankle and knee joints, foot pressure, and vertical impact force. Based on the test results, the main points of the design of nurses' shoes are summarized as follows :(1) The outsole with large thickness in the metatarsal region of the sole is easy to produce low metatarsal pressure and vertical impact force, which can reduce the discomfort of the back; (2) The midsole is made of EVA or PU material, which is more helpful to reduce the sole pressure and increase the comfort of the whole body and feet than the sole of the rubber material alone. (3) Outsole with a heel height of about 2.5cm will produce lower heel pressure and vertical impact force, reducing the force on the front sole of the foot. Therefore, it is suggested that the design of nurses' shoes should focus on the heel height, sole thickness and sole material, and develop nurses' shoes specially for nurses to wear, which will help improve the health of nurses.

Acknowledgments

This paper is the research result of Wenzhou major science and technology project "Collaborative Research and Demonstration of Women's occupational health Shoes based on long-term fatigue Assessment (ZG2021032)."

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