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EFFECTS OF SLIPPERINESS OF THE GROUND AND DEPTH OF SHOE GROOVES ON KNEE JOINT TORQUES AND MUSCLE ACTIVITY DURING WALKING

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SUMMARY

In this research the effect of ground slipperiness and depth of shoe grooves on knee joint forces and torques are tested and analyzed. 22 male students are used as test subjects, and were asked to walk with two pairs of shoes with different groove depths and on different ground surface conditions. Kinematics of their walking and ground reaction forces were measured by motion analysis system and force plate respectively. Forces and torques on knee joint is then calculated by inverse dynamics. At the end, results of tests are analyzed to conclude the effect of slipperiness and shoe groove depth on gate parameters.

INTRODUCTION

Walking is one of the major human physical activities during day time life, and shoes make the only contacts of legs with the ground. Any changes in shoes or ground surface properties will affect gate parameters [1, 2]. Kai Way Li et al. (2006) measured the effect of shoe groove depth on friction coefficient between the shoe and the ground on different ground conditions [3]. Matthew A.Nurse et al. (2005) studied the effects of shoes inside texture on gate parameters and ankle joint forces and torques [4]. In this research we analyze the effects of shoe grooves depth and ground surface slipperiness on knee joint torques and muscle activities during gate analysis.

METHODS

22 male students of age 19-21 by normal BMI (Body Mass Index) 22-23 and natural pattern of walking were selected as subjects. Natural pattern of walking was expressed as a walking without any abnormality detectable through observation. Every subject was asked to walk by similar velocity in all parts of the tests which was free speed walking that is introduced for this age group (18-49) as 98-138 steps per minute. The shoes that were used for these tests were 2 sets of OXFORD standard shoes with 1mm and 5mm depths of flat groove [3]. Subjects were asked to walk by each pair of shoes on 2 surface conditions, one was dry surface and the other one was slippery surface (made slippery by soapsuds); therefore there were 4 states of test for each subject. GRF (Ground Reaction Force) was measured by two piezoelectric force plates (KISTLER 9286A), and movements were captured by **Vicon** motion analysis system with 6 IF (Infra Red) cameras. 5 markers were put on each leg (3 on foot, one on knee, one on hip). Although walking seems to be a 2-D motion, in this research kinematics and dynamics of motion is solved in 3-D coordinates. Two successful walking of each subject in each of 4 mentioned states was recorded.

Kinematic characteristics of motion were calculated by inverse kinematics and motion analysis systems output (Vicon motion analysis system gives 3-D coordinates of markers.). Inertia characteristics of the limbs were obtained from total mass of the subjects and anthropometric ratios. We used Newton-Euler equations to calculate joint forces and torques.

RESULTS AND DISCUSSION

The focus of this study was on knee joint, therefore joint forces and torques are calculated only for this joint. Joint torques were calculated only in sagittal plane and during stance phase.

Knee joint torques of one test subject for shoe groove depths of 1mm and 5mm are shown in Figure 1 and Figure 2 respectively as an example. In this Figures changes in knee joint torques in sagittal plane are shown during stance phase, for the 4 conditions described before.

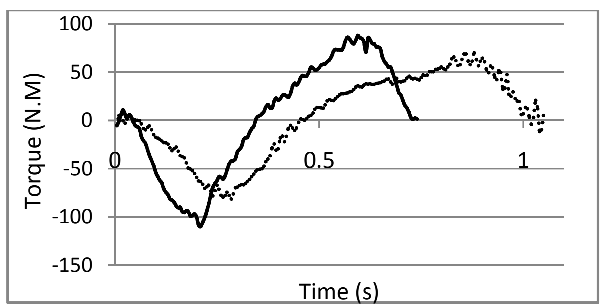

Figure 1: Knee joint torques in sagittal plane during stance phase of walking by 1mm grooved shoes on dry surface (solid line) and slippery surface (dashed line).

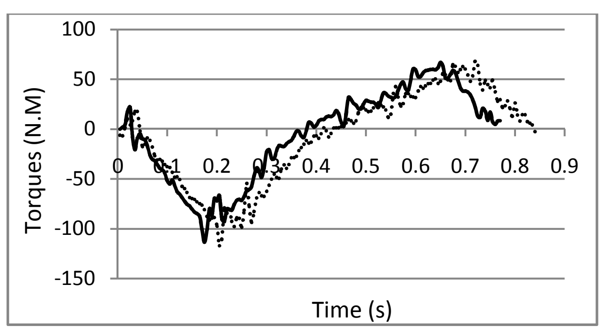

Figure 2: Knee joint torques in sagittal plane during stance phase of walking by 5mm grooved shoes on dry surface (solid line) and slippery surface (dashed line).

Both Figure 1 and Figure 2 show an increase in duration of stance phase on slippery surface compared to dry surface. Magnitudes of joint torques are also seemed to be higher when walking on dry surface. Average of 3 quantities, total mechanical work, duration of stance phase, and mean value of joint torque are calculated for all 176 test of 22 test subjects, and the results is shown in table 1.

Comparison between values in table 1 indicates that knee joint torque in sagittal plane is higher when walking on a dry surface compared to slippery surface, and the effect of this slipperiness is decreased from %14 to %8.6 by increasing the depth of shoe grooves. A similar change in total mechanical work is also seen in this table. By making the surface slippery, total mechanical work in knee joint is reduced %11 when using 1mm grooved shoes, and %6.8 when using 5mm grooved shoes.

Stance phase duration is increased by increasing the slipperiness of the surface. Like the other two parameters, the effect of making the surface slippery is reduced for this parameter by increasing the depth of the groove from 1mm to 5mm.

It is shown in table 1 as well as almost all of the test subjects that by increasing the duration of stance phase, which means decreasing walking speed, mean joint torque and total mechanical work in knee joint will be reduced.

CONCLUSION

As seen by the results of these tests, it is concluded that despite common thoughts, increasing friction coefficient between shoe and the ground may not be always a useful thing. For example it is shown here the total mechanical work in knee joint, which is an indicator of flexor-extensor muscle activity, is reduced by reducing the friction.

It is seen in almost all of the tests that increasing the depth of the grooves reduces the difference between torques, total mechanical works and even stance phase durations on dry and slippery surfaces. It may be explained by that, raising depth of groove increases compliance of the contact and reduces its rigidity and therefore has a similar effect to reducing of friction. So by increasing the depth or groove, effect of decreasing the friction on reduction of contact rigidity will be reduced.

The effect of muscle co-contraction was not considered in this study, but it is possible that when the ground friction is reduced, body tend to increase muscle co-contraction in order to increase stability. We suggest adding EMG measurement to the tests in further studies to make it possible to consider muscle co-contraction.

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Table 1: Average values of mean joint torque on knee (during stance phase), time duration of stance and total mechanical work on knee joint during stance in sagittal plane for all test subjects.

	Average moment on knee (N.M)	Time duration (s)	Total work (J)
Dry, 1mm	54.57	0.7558	40.092
Slippery, 1mm	46.98	0.79	35.73
Dry, 5mm	53.33	0.778	40.05
Slippery, 5mm	48.769	0.785	37.33