SLIP ANTICIPATION EFFECTS ON HIP/KNEE KINEMATICS PART II: GAIT ON GLYCEROL CONTAMINATED FLOORS

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INTRODUCTION

A significant number of accidental injuries and deaths are attributed to slips and falls. The US National Health Interview questionnaire of 1997 showed that 64% of falls at work resulted from slipping, tripping or stumbling (Cham R., 2001). Causes of slips involve complex interactions of environmental and human factors (Redfern M.S., 2001). In order to better understand the impact of body reactions on the outcomes of a slip, i.e. recovery or fall, this paper will focus on the human factors, in particular, the knee and hip kinematics. Previous studies have shown knee flexion reactions recorded about 200 ms into stance were generated in the slipping leg as an attempt to recover balance during slips (Cham R., 2001). The goal of this study is to investigate the impact of proactive strategies, i.e. gait adaptations at heel contact (HC) with the slippery surfaces, on the slip severity. The impact of hip and knee kinematics on slip distance was compared between unexpected and anticipated slips.

METHODS

Equipment: Subjects walked naturally across a vinyl tile walkway instrumented with 2 Bertec force plates (FP), each foot contacted one FP. The contaminant (glycerol solution) was applied on the left FP, the slipping foot was the stance leg and the right foot was the trailing leg (no glycerol was applied on the right FP). Subjects wore a safety harness to prevent injury. Ground reaction forces were recorded at 600 Hz. Whole body motion (8 Vicon 612 motion capture cameras) was recorded at 120 Hz. Markers on the shank, thigh and pelvis were used to derive 3D kinematics of the knee and hip. (Fig 1)

Protocol: Five healthy subjects, aged 35 years or less, were screened for neurological, vestibular and orthopedic abnormalities prior to their recruitment. Subjects were told that the initial trials were dry. Without the subject's knowledge, a glycerol solution was applied to the left FP prior to the 3rd trial, 'unexpected' slippery condition. The subject was then informed that all of the following trials might be slippery. After 5 dry trials, the glycerol solution was applied to the left FP, the 'alert' slippery condition. After 5 more dry trials, the glycerol solution was applied one final time with the subjects' knowledge, the 'no-doubt condition'.

Data processing and analysis: A biomechanical rigid body model (left/right shank, left/right thigh and pelvis) was built to derive the 3D kinematics of the knee and hip (Fig 1). Flexion angles of the knee were derived by considering the rotation of the shank's local frame with respect to the thigh's local z-axis. Similarly, the hip angle was derived from the rotation of the thigh's local frame with respect to the pelvis' local sagittal axis. The knee and hip angles, measured during standing anatomical position, were subtracted from the absolute measurements during gait trials. Within-subjects repeated measures ANOVA were conducted on the slip distance to investigate the impact of knee/hip angles, evaluated at

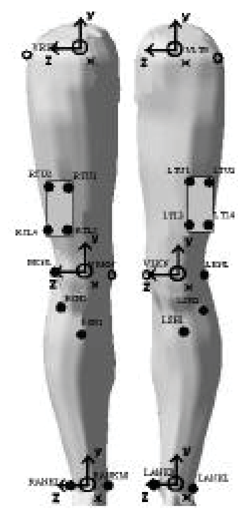

Fig 1: Biomechanical model of lower body used to derive 3D kinematics of hip/knee.

the time of left heel contact, on slip severity. HC time was determined using FP data.

RESULTS AND DISCUSSION

At HC time, increased hip extension and knee flexion were recorded (Fig 2 and 3). Fig 2 also shows that, later in stance, knee flexion is used as a recovery strategy (Cham R., 2001).

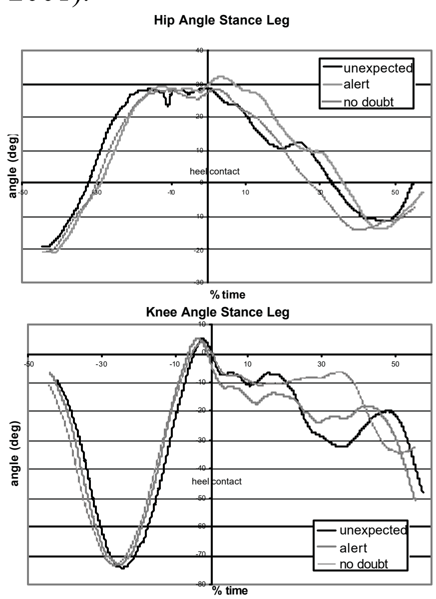

Fig 2: Typical profiles of left knee and hip angles during each slip condition. HC occurs at zero % time. Positive corresponds to extension while negative is flexion.

Right hip/knee angles at left HC showed no statistically significant impact ($p > 0.1$) on the slip distances. The relationships between slip distance and both the left hip/knee angle were statistically significant ($p < 0.05$). At HC, left hip extension and knee flexion increased significantly when subjects anticipated slippery conditions (Fig 3).

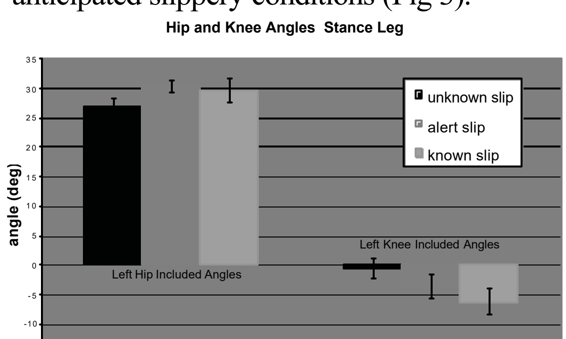

Fig 3:Angle at HC for the left hip/knee for each slippery condition. Error bars are standard errors.

Gait adaptations due to slippery surfaces anticipation in fewer falls and smaller slip distances (Table 1).

Subject number	Slip Anticipation Condition	Slip Distance (mm)	Outcome
1	Unexpected	76.37	Recovery
2	Unexpected	129.042	Fall
3	Unexpected	34.52	Recovery
4	Unexpected	351.44	Fall
5	Unexpected	151.33	Fall
1	Alert	47.42	Recovery
2	Alert	178.97	Fall
3	Alert	43.78	Recovery
4	Alert	73.93	Recovery
5	Alert	34.63	Recovery
1	No-doubt	23.75	Recovery
2	No-doubt	113.14	Recovery
3	No-doubt	41.89	Recovery
4	No-doubt	-16.29	No Slip
5	No-doubt	1.91	No Slip

Table 1: Raw slip distances and slip outcomes.

DISCUSSION

At HC, anticipation conditions showed a significant increase in hip extension and knee flexion. These gait adaptations, were associated with an improved chance of completing a successful recovery after the slip. It is believed that an increase in hip extension and knee flexion recorded at HC during the anticipation conditions "improved balance". This anticipatory strategy resulted in reduced slip distances and less falls. Other gait adaptations, changes in foot-floor angles, exist and are beyond the scope of this paper. Those results are reported in another ASB submission (Margerum S., 2003).

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