INVESTIGATING THE LINK BETWEEN KINEMATIC DEVIATIONS AND RECOVERY RESPONSE TO UNEXPECTED SLIPS

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INTRODUCTION

Falls are one of the main contributors to occupational injuries. Falls account for approximately 24% of non-fatal injuries and 13% of fatal injuries in the workplace [1]. Slipping is the leading cause of falling accidents that occur on the same level ground. In response to a slip, a complex recovery response is initiated to prevent the fall. While this recovery response is critical for regaining balance, the sensory modalities that trigger the response are not well understood.

Previous research has indicated that degradation in the sensory system due to aging may increase slip risk [3]. As a first step towards identifying the systems responsible for detecting a slip, the order of deviations to the lower-body joint angles (relevant to proprioception) and vertical foot forces (relevant to somatosensation) has been identified. Vertical forces and slipping-leg knee angles are known to deviate before the onset of the recovery response or other joint angles indicating that foot somatosensation and knee angle may be responsible for detecting the slip [4]. This study aims to continue to examine the relationship between kinematic deviations and motor response by correlating the onsets of deviations with the onset of muscle response.

METHODS

Nine healthy young adults (4 male and 5 female, age=22-33 yrs) participated in this study. Subjects were fitted with a set of 56 reflective markers, 4 surface electromyography (EMG) electrodes. Subjects were donned with a harness to prevent falling due to slipping throughout the trials. All subjects were provided tight-fitting clothing and standard shoes to minimize marker error and ensure constant shoe-floor friction conditions, respectively.

Subjects were informed that the floor would be dry. The five known dry conditions were followed by an unexpected slip trial. The unexpected slip was induced by applying a thin layer of a diluted glycerol contamination (90% glycerol and 10% water) to the floor surface above the force platform [4]. Motion capture system (Motion Analysis Co, Santa Rosa, CA) collected marker data to compute ankle, knee, and hip joint angles. Subjects walked across four force plates that measured ground reaction forces (GRF). During slipping trial, slipping contaminant was applied on the third force plate. All subjects gave informed consent prior to their participation and this research was approved by the University Institutional Review Board

Several variables were measured that are believed to be relevant to sensory afferents. Joint angles of the ankle, knee and hip for ipsilateral to the slip were measured for proprioception. Vertical and shear GRFs for the slipping leg were collected via forceplate for somatosensation at foot. Four surface EMG signals (Delsys, Boston, MA) were collected to determine the motor response to unexpected slip at the following muscles:(1) rectus femoris (RF), (2) tibialis anterior (TA), (3) medial gastrocnemius (MG), and (4) medial hamstring (MH).

The time that variables deviated during a slip from the baseline walking conditions was denoted deviation time (*TimeDev*). *TimeDev* was defined as the minimum time when the normalized deviation of each variable from the baseline exceeded 1.96 similar to [4], which is equivalent to 95% confidence interval of the baseline walking (Fig 1).

$$Deviation = \frac{Variable_{perturbed} - \text{mean}\left(Variable_{baseline}\right)}{\text{stdev}\left(Variable_{baseline}\right)}$$

A repeated measures ANOVA was used to investigate *TimeDev*'s for each variable were significantly different. Pearson's correlation analysis was performed to determine how sensory responses (joint angles and ground reaction forces) were related to motor response (muscle activation). Significance level was set to 0.05 (SPSS v17, Chicago, IL).

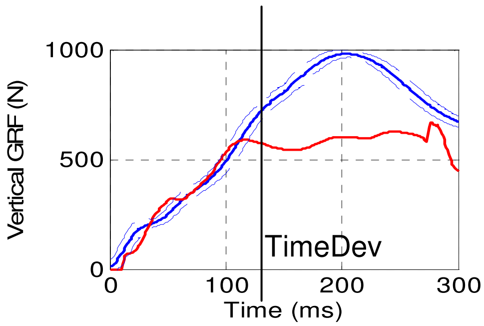

Fig 1 Representative vertical GRF for the mean baseline (solid blue) +/- standard deviations (dashed blue) and the slip (red). The vertical line represents the time of deviation.

RESULTS AND DISCUSSION

A repeated measures ANOVA found that *TimeDev*'s were significantly different ($p<0.01$). The order of deviations were similar to [4] with ground reaction forces deviating first followed by knee angle, ankle angle and hip angle. Anterior/posterior ground reaction forces deviated around the same time as the vertical force, while medial-lateral force deviation occurred later in stance. Note that all motor responses to unexpected slip occurred after the kinematic deviations to the ipsilateral leg. The order of muscle onsets were medial hamstring, tibialis anterior, medial gastroc and then rectus femoris similar to published research on unexpected slips [5].

Pearson's correlation analysis found that *TimeDev*'s for ankle ($r=0.73$, $p=0.027$) and hip ($r=0.68$, $p=0.043$) joint angles were significantly correlated with *TimeDev* for MH. *TimeDev* for hip ($r=0.70$, $p=0.037$) joint angle was significantly correlated with *TimeDev* for TA. None of the kinematic deviations were correlated with MG or RF.

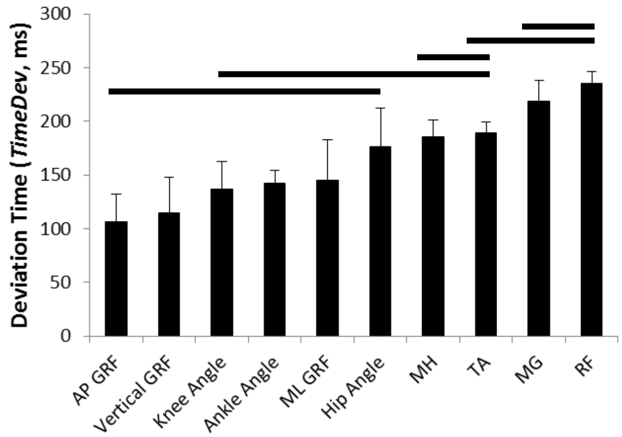

Fig 2 Average deviation times (*TimeDev*) for each variable. Error bar is ± SE. Thick lines represent groups of variables that have no statistical significance.

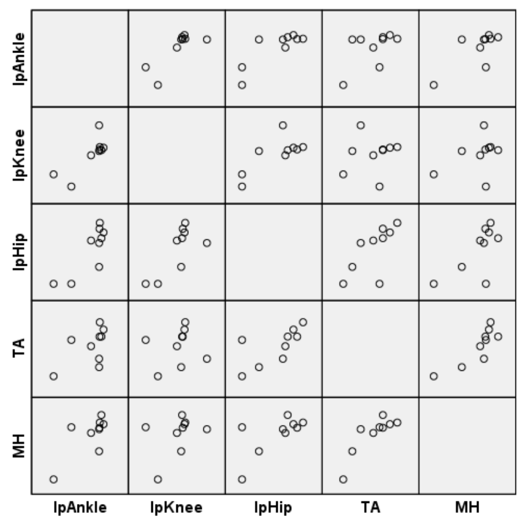

Fig 3 Scatter plot showing correlation between *TimeDev*'s for ankle, knee, hip joint angles, TA and MH.

CONCLUSION

While ground reaction forces and knee joint angles deviated first, they were not correlated with the timing of muscle onset in response to slipping. Several kinematic measures deviate prior to muscle onset and muscle onsets were best correlated with ankle and hip angles (which deviate later in stance). This may indicate that the central nervous system waits for multiple afferents to deviate before initiating the recovery response. Therefore, sensory deficits to any of the lower-body systems may inhibit the body's ability to respond to a slip.

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