Initial Condition Variables and Age Group as Determinates of Slip Severity

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INTRODUCTION

Slip/fall research has primarily focused on subjects' postural reactions generated in response to slipping, based on the assumption that slip outcomes (recovery or fall) are predominantly governed by reactionary biomechanics. Although this is certainly true, subjective gait biomechanics likely contribute to the initial conditions affecting slip magnitudes as well. The relationships among initial condition variables, age group, and slip magnitude resulting from stepping onto a slippery surface are reported herein.

METHODS

A total of 27 healthy adults, 11 older individuals aged 55 to 67 years and 16 younger individuals aged 20 to 33 years old, participated in the study (Table 1). Prior to participation, each individual signed a consent form approved by the University of Pittsburgh Institutional Review Board. Exclusionary criteria included a history of neurological, orthopedic, cardiovascular and pulmonary abnormalities as well as any other difficulties hindering normal gait.

Table 1: Average subject age, height, and weight with standard deviations.

	Fem	Male	Age	Height (cm)	Weight (kg)
Young	9	7	23.5 (3.2)	171.2 (8.9)	67.6 (10.5)
Old	7	4	60.9 (4.0)	166.2 (8.1)	78.2 (10.9)

Subjects walked on a raised platform, surfaced with Armstrong commercial tile while an eight camera Vicon 612 measurement system acquired 3D motion data at 120 Hz from markers placed on their left feet. Ground reaction forces were recorded at 1080 Hz from two Bertec forceplates located near the center of the 9 m gait path. All participants wore the same brand/model of appropriately sized polyvinyl chloride hard-soled shoes. A harness protected subjects from ground contact injuries.

The gait start location was adjusted to ensure appropriate contact with the forceplates for each subject walking at their self-selected comfortable pace. After sufficient practice, subjects were informed that the first few trials would be dry and two to three trials were collected. Then, without a subject's knowledge, a diluted glycerol solution (75% glycerol, 25% water) was applied onto the left (leading) foot forceplate (0.75 x 0.4 m) and another gait trial was conducted. The coefficient of friction of the shoe-floor interface was 0.53 and 0.03 for the dry and slippery surfaces, respectively, as measured with the English XL VIT slipmeter (ASTM F1679). To mask contaminate application clues, subjects faced away from the gait path for one minute between trials while listening to loud music, all trials were conducted with lights dimmed, and subjects were instructed to focus on a target centered on the wall at the end of the gait path during ambulation. To reduce anticipatory and learning gait adjustment effects, analysis for this paper has been limited to one (unexpected) slip.

RESULTS AND DISCUSSION

Slip type was categorized as hazardous (slip distance > 10 cm) or non-hazardous (slip distance < 10 cm); note, none of the non-

hazardous slips resulted in falls. Four of eleven older subjects and six of sixteen younger subjects experienced non-hazardous slips as illustrated in Figure 1.

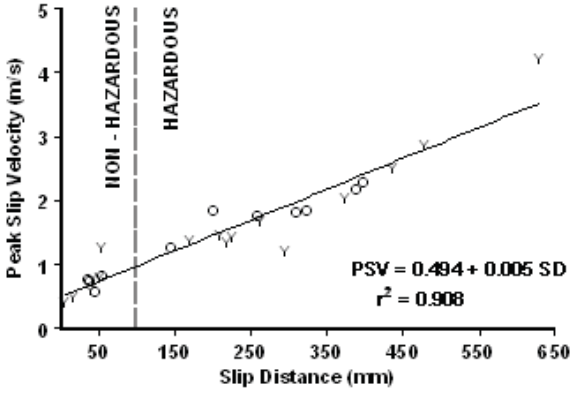

Figure 1: Peak slip velocity (PSV) versus slip distance (SD) for Young (Y) and Older (O) subjects.

To better understand why some subjects experienced non-hazardous slips while others did not, several temporal and spatial gait variables were derived: **CAD**, cadence (steps/min); **SLR**, step length ratio (step length normalized to left leg length); **GS**, gait speed (m/s); **FFA**, foot-floor angle at heel strike (deg); **FFAS**, slope of foot-floor angle at heel strike (deg/s); **LLR**, left foot normal force rate of change after heel strike (N/s). Some of these gait variables were well correlated (Table 2) including SD and PSV (Figure 1) which were both well correlated with SLR, FFA, FFAS, and LLR.

Table 2: Variable correlations

SD	0.95	-0.34	0.51	0.24	0.48	-0.47	0.49
	PSV	-0.37	0.57	0.25	0.46	-0.46	0.55
		CAD	-0.18	0.51	-0.38	0.14	0.00
			SLR	0.51	0.67	-0.70	0.67
				GS	0.17	-0.43	0.61
					FFA	-0.73	0.22
						FFAS	-0.38
							LLR

A series of two-factor (age group and slip type) ANOVAs were conducted on these variables. In general, there were significant differences (except for LLR and GS) between hazardous and non-hazardous slips. Significant age-group differences were seen in SLR, FFA and FFAS (Figure 2). No secondary interaction (age, slip type) effects were significant.

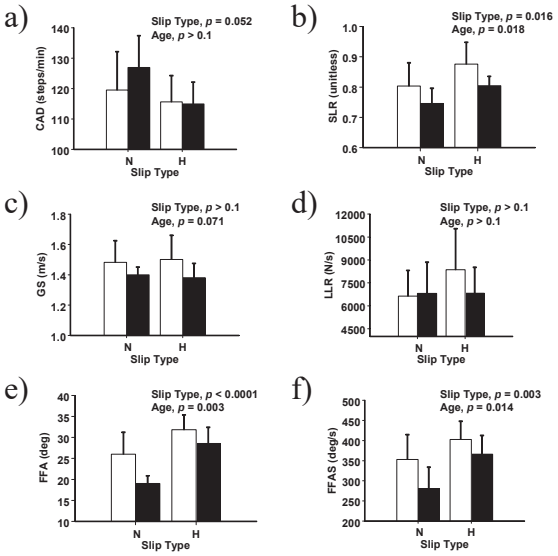

Figure 2: Associations among age-group: unfilled = young, filled = old; slip type: (N)on-Hazardous and (H)azardous; and variables of interest, a) CAD, b) SLR, c) GS, d) LLR, e) FFA, and f) FFAS. Means with standard deviations illustrated.

Because they can be determined *a priori*, initial condition variables may be useful predictors of slip severity. The outcome of a hazardous slip (fall or recovery) was not differentiable based on these variables due in large part to active recovery reactions which play a critical role in a subjects' attempts to regain balance.

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