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Recovery responses to surrogate slipping tasks differ from responses to actual slips

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Abstract

Slipping and slip-related falls are a common and potentially dangerous problem, especially for older adults. We believe that it is possible to train compensatory stepping responses of older adults to reduce the incidence of slip-related falls. However, such an approach requires further understanding of the causal biomechanical distinctions between a successful and an unsuccessful recovery effort. Surrogate tasks are often used to study complex biomechanical events associated with large postural disturbances. Although surrogate tasks enhance experimental control over one or more elements of a generally more complex event, such control may change the task of interest by imposing biomechanical constraints that reduce the validity of the surrogate. The purpose of the present study was to quantify the differences in lower extremity and trunk kinematics following a simulated slip versus an actual slip. We hypothesized that the simulated slips would be less variable than real slips and would result in significantly different, and less realistic recovery kinematics. Twenty-two healthy young adults were subjected to unexpected slips using a custom slipping platform and artificial ice. Biomechanical variables associated with the slipping foot were significantly less variable in those slips induced with the platform compared to slips induced with the artificial ice. Significant differences between successful and unsuccessful recovery efforts were found for lower extremity and trunk kinematics on both types of slipping surface. Notably, 40% of the variables for which between surface differences were significant were also those variables that distinguished successful and unsuccessful recovery efforts on the two surfaces. The results suggest that slips induced using artificial ice more accurately reflect the type of slips that occur in the community.

Keywords: Locomotion; Falling; Dynamic equilibrium; Slip

1. Introduction

Fall-related injuries, up to 50% of which result from slips [1], and even the threat of fall-related injuries, can exert a considerable effect on the quality of life of older adults. For older adults, a particularly devastating fall-related injury is hip fracture. Since 90% of hip fractures result from falls, preventing falls seems a logical and plausible approach to reducing the incidence of these injuries. Characterizing the biomechanical requirements of restoring dynamic equilibrium following a slip, and the relationships between the performance capabilities of older adults and performance requirements of the recovery task, are important objectives that underlie the design, validation and implementation of clinically relevant interventions to reduce the number of falls and fall-related injuries to older adults.

Laboratory protocols often simulate slips through the use of sliding platforms or rollers [2,3]. Such devices provide control over variables such as when a slip occurs, which foot is slipped, the direction of the slip and the distance through which the slip occurs. However, slipping events in the community are highly variable with respect to cause and effect. Therefore, biomechanical differences between the actual and surrogate events may be considerable. In addition, these devices purportedly allow multiple ‘‘surprise’’ slips by randomizing slipping and non-slipping trials. However, anticipatory adjustments occurring in trials subsequent to an initial surprise slip are known to occur [4].

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Recovering from a slip is a complex and time critical motor task. There is evidence that the ability to control the slipping foot and control the body center of mass relative to the base of support are important factors in whether an individual is able to regain his or her balance [5,6]. The recovery response may be sensitive to the initial biomechanical conditions such as positions, velocities, and accelerations of the limbs and torso preceding the disturbance as well as after the disturbance. If the increased experimental control associated with simulations of slips subtly or grossly alters aspects of the task, the overall effect would be to diminish the extent to which the simulation mimics the actual event. The present study was undertaken with the goals of quantifying the differences in lower extremity and trunk kinematics following a simulated slip versus an actual slip, and to determine whether the outcome (fall versus recover) was influenced by the methodology. Young adults were selected for study because we believe that the abilities of healthy young adults provide a reasonable estimate of the biomechanical boundaries that limit recovery. We hypothesized that a simulation of a slip in which greater experimental control was exerted would be associated with a less variable response (indicated by smaller standard deviations in the measured variables) and that some kinematic measures would differ significantly from those following a more realistic slip.

2. Methods

Twenty-two healthy young adults (11 males, age 25 ± 5 years, height 171 ± 10 cm, mass 69 ± 12 kg) were subjected to two types of unexpected slips during a single laboratory visit. Slips were induced using both a custom slipping platform and previously described "artificial ice" [5]. The slipping platform consisted of three 120 cm × 240 cm raised plywood platforms laid end-to-end to create a 120 cm × 720 cm walkway. The middle platform had four 183 cm long precision ground rails aligned parallel to the direction of walking and on which two surfaces (31 cm × 120 cm), one for each foot, moved along linear bearings. Each surface could slide a maximum distance of 62 cm in the direction of walking. Under normal circumstances the positions of the surfaces were secured by pins. During trials in which a slip was to be induced the pins were released remotely using solenoids. The artificial ice consisted of a 120 cm × 120 cm Plexiglas sheet, the surface of which was coated with a film of mineral oil prior to a slipping trial. Since a slip on artificial ice was unexpected and kinematically unconstrained, similar to a slip occurring in the community, this surface was considered the gold standard. Slipping device order was distributed and 12 of the subjects slipped first on the artificial ice. Before any data were collected, subjects were told that in the event of an induced slip, they should attempt to regain their balance but in doing so, avoid grabbing the safety harness rope, which was attached to the front of the chest component of the safety harness. All subjects gave written informed consent prior to participation in the institutionally reviewed and approved protocol.

Kinematic data were collected using an eight camera motion capture system (Motion Analysis, Santa Rosa, CA) that tracked the motion of 23 passively reflecting markers at 60 Hz (Fig. 1). The markers were used to create a 13-segment rigid body model [7]. A safety harness prevented a fall to the walking surface. The safety harness was attached to a track on the ceiling using a dynamic rope that was adjusted for each subject so that, if they should fall, their hands and buttocks could not contact the walking surface. A load cell was placed in series with the dynamic rope so that the timing of and extent to which the harness supported the subject could be quantified.

2.1. Control walking and artificial ice trials

Each subject was instructed to walk across the floor at a self-selected speed and to target a specific floor location with their right foot. The target was marked as a red "X" on a 120 cm × 120 cm piece of Plexiglas placed on the laboratory

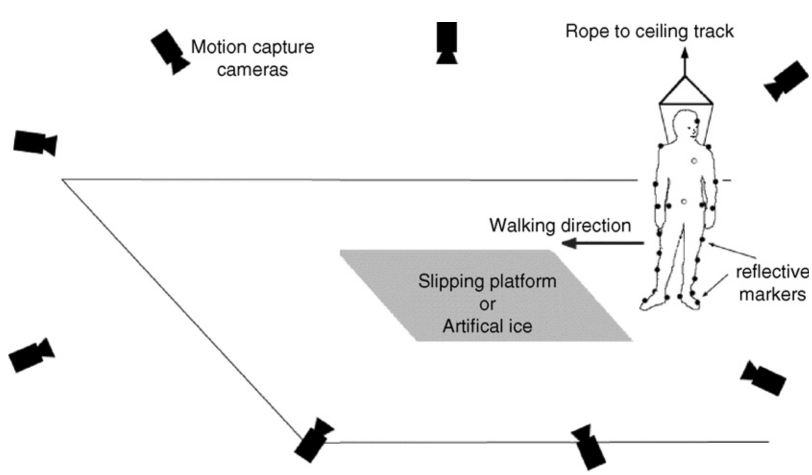

Fig. 1. Experimental set-up and marker set description. White-centered markers indicate the reflector is hidden in the frontal view.