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Constraining the arms during a slip perturbation results in a higher fall frequency in young adults

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ABSTRACT

Slip and fall incidents are a major health concern. Although studies have reported the mechanical benefits of upper extremity responses during a slip to regain balance, it is not currently known if reactive arm motions aid in the recovery of a slip event. Sixty-four healthy young adults were randomized into 4 gait conditions: arms free, both arms constrained, contralateral arm to the slipping foot constrained and ipsilateral arm to the slipping foot constrained. While wearing a protective harness, participants traversed a 10-m walkway and were exposed to an unexpected slip. The group with their arms constrained exhibited a higher proportion of falls compared to the group with the arms free (62.5% vs 18.8%). In addition, individuals assigned to the contralateral arm constraint group exhibited a significantly higher proportion of falls compared to the group in which the ipsilateral arm was constrained (68.8% vs. 31.2%). Our findings suggest that arm motions aid in the recovery of balance during a slip perturbation. Motion of the arm contralateral to the slipping foot appears to be most important. Training upper extremity reactive responses training the arms may be a useful adjunct to fall prevention programs fall prevention.

1. Introduction

Slips are a major health hazard as slip-induced falls rank in the second highest cause for emergency department visits in both the workplace and non-occupational settings (Chambers, Ibrahim, Etches, & Mustard, 2015). Given the high financial burden associated with slip and falls, research in this area has focused on understanding how individuals recover from a slip event. Knowledge of the influence of reactive movements in response to a slip may provide important information on whether these motions are beneficial to regaining balance.

Lower extremity responses to slip perturbations previously have been described (Beschorner, Redfern, & Cham, 2013; Brady, Pavol, Owings, & Grabiner, 2000; Cham & Redfern, 2001; Heiden, Sanderson, Inglis, & Siegmund, 2006; Kim, Joo, Liu, & Sohn, 2019; Lockhart & Kim, 2006; Marigold & Patla, 2002; Parijat & Lockhart, 2008; Qu, Hu, & Lew, 2012; Rasmussen & Hunt, 2021; Ren et al., 2022; Wang, Bhatt, Liu, & Pai, 2020). In terms of upper extremity kinematics, arm movements also have been reported in response to a slip perturbation (Lee-Confer, Bradley, & Powers, 2022; Marigold, Bethune, & Patla, 2003; Merrill, Chambers, & Cham, 2017; Nazifi, Beschorner, & Hur, 2020; Troy, Donovan, & Grabiner, 2009). Specifically, it has been reported that the arms demonstrate bilateral flexion in response to a slip, and this motion serves to shift the center of mass anteriorly to counter the backwards loss of balance (Marigold et al., 2003). It also has been reported that arm motions during slipping reduce trunk extension velocity which aids in

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regaining balance (Troy et al., 2009).

A previous study from our group reported that multi-plane arm motions are important in recovering from a slip event (Lee-Confer et al., 2022). Specifically, abduction excursion of the arm contralateral to the slipping foot was found to be significantly greater than the sagittal plane excursion of the arm in those who successfully recovered from an unexpected slip (Lee-Confer et al., 2022). From a biomechanical perspective, contralateral arm abduction likely reduces lateral excursion of the center of mass excursion during slipping, similar to what has been described during laterally directed platform perturbations (Grin, John, & Allum, 2007).

While upper extremity responses during slipping have been described, and their theoretical contributions to regaining balance proposed, the impact of the arms on regaining balance has not been experimentally tested during a slip perturbation. This is important as most prevention programs focus on facilitating lower extremity responses to prevent falls (i.e. lower extremity strengthening, reactive exercises, etc.) (Karinkanta, Piirtola, Sievanen, Uusi-Rasi, & Kannus, 2010). If it can be shown that upper extremity responses play a role in slip recovery, incorporation of upper extremity exercises to fall prevention programs could be advantageous.

The purpose of the current study was to determine the influence of arm motions on fall frequency following an unexpected slip event. To achieve this aim, we used an arm constraint protocol to answer two questions: Do the arms assist in the recovery of a slip event? If so, which arm is most important? We hypothesized that individuals who slip with both arms constrained will demonstrate a higher fall frequency compared to those who slip with the arms unconstrained. We also hypothesized that individuals who slip with their contralateral arm constrained (in relation to the slipping foot) will demonstrate a higher fall frequency compared to those who slip with the ipsilateral arm constrained.

2. Methods

2.1. Participants

Sixty-four healthy adults between the ages of 21 and 35 participated in this study (22 males and 42 females). Prior to participation, all were informed of the nature of the study and provided written informed consent as approved by the University of Southern California Health Science Campus Institutional Review Board. Participants completed a medical questionnaire to screen for possible conditions that could jeopardize their safety by participating in the study. Specifically, individuals were excluded from participation if they reported any of the following: neurological or orthopedic conditions that would affect gait, current muscle strains or joint sprains, recent bone fractures, previous back injuries, or individuals who potentially were pregnant.

2.2. Instrumentation

All gait trials were conducted on a 10-m walkway. A Teflon coated floor tile (California Technical Plating, San Fernando, CA, US) was imbedded into the walkway and camouflaged such that the coloring of the tile matched the non-Teflon tiles. To prevent falls during testing, a fall-arresting body harness (Miller Model 550–64, Dalloz Fall Protection, Franklin, PA, USA) secured with an 8 mm climbing rope was attached to an overheard low-friction trolley. An Omega S-beam load cell (Omega Engineering Inc., Norwalk, CT, US) connected the climbing rope to the trolley system was used to measure the amount of supported bodyweight during the slip perturbation trials. To control for the influence of footwear, participants were fitted with a pair of oxford dress shoes with a standard rubber outer sole (Bates Footwear, Richmond, IN, US).

2.3. Procedures

Participants were randomly assigned to 1 of 4 arm constraint conditions: 1) both arms free, 2) both arms bound, 3) contralateral (left) arm bound, or 4) ipsilateral (right) arm bound. Each arm constraint group consisted of 16 participants. The groups were similar in terms of sex distribution, age, height, and weight (Table 1).

Constraint of arm movements was achieved by wrapping an adjustable polypropylene strap around the thorax and upper arm, approximately 2–3 in. above the elbow. Additionally, both wrists were fastened to the harness using padded wrist restraints (Fig. 1). For participants in the contralateral arm bound group, the strap was placed around the thorax and left upper arm (approximately 2–3 in. above the elbow), and their left wrist was placed in the restraint. Similarly, participants in the ipsilateral arm bound group had the strap placed around their thorax and right upper arm and the wrist was secured with a restraint.

Prior to testing, participants were allowed to accommodate to the provided footwear. An adjustable fall arresting harness was then fit to each participant such that the hip would not be permitted to drop below a distance equal to 35% of their height (Yang & Pai, 2011). The lighting in the laboratory was dimmed so the light measurement over the Teflon surface was 4 fc (approximately 43 lm).

Table 1
Participant characteristics for the four arm constraint conditions. $n = 16$ for each group.

	Both Arms Constrained	Both Arms Free	Contralateral Arm Constrained	Ipsilateral Arm Constrained	Sig.
Age (years)	26.1 ± 3.4	25.0 ± 2.2	24.8 ± 2.8	24.9 ± 4.2	$p = 0.64$
Height (m)	1.71 ± 0.1	1.68 ± 0.1	1.67 ± 0.1	1.65 ± 0.1	$p = 0.27$
Weight (kg)	65.0 ± 9.9	64.4 ± 9.4	65.2 ± 10.6	62.8 ± 9.4	$p = 0.56$
Sex (M/F)	6/10	6/10	5/11	5/11	$p = 0.96$

Fig. 1. Arm constraint positioning used in the current study. Ipsilateral arm constrained (top left), contralateral arm constrained (top right), both arms constrained (bottom left), no arms constrained (bottom right).

This ensured that the participants had ample lighting to walk safely while also providing additional concealment of the Teflon surface. Participants were instructed to conduct multiple practice walking trials to adjust to the harness system and dimmed lighting conditions and to achieve a consistent walking speed of 1.35–1.5 m/s. For all walking trials, participants were instructed walk naturally and look straight-ahead.

Once acclimated to the instrumentation and procedures, participants performed 4 non-slip walking trials. Between each trial, participants faced away from the walkway for 1 min so that they would be uncertain as to the trial in which the contaminant would be placed on the floor to induce a slip. Loud music was played during each of the 1-min breaks between trials to act as an additional distraction and avoid the participant hearing the application of the contaminant. After obtaining the 4 non-slip walking trials, mineral oil contaminate was placed on the Teflon tile and a 5th walking trial was performed.

Following the slip trial, participants were asked if they had anticipated the slip or if they had seen the contaminant. Any anticipation or observation of the contaminant resulted in the subject being excluded from this study. All participants slipped on their right foot and were only exposed to 1 slip during the study. For purposes of this study, the outcome of the slip, recovery or fall, was determined by the load cell. A slip outcome was classified as a fall if the individual placed >30% of their body weight onto the harness system (Yang & Pai, 2011).

2.4. Statistical analysis

A chi-square analysis was performed to test whether individuals with their arms constrained demonstrated a higher fall frequency compared to those who slip with their arms unconstrained. A chi-square analysis also was performed to test for differences in fall frequency between the contralateral arm and ipsilateral arm bound conditions. Analyses were performed using SPSSS 16.0 statistical software (SPSS, Chicago, IL, USA) and significance levels were set at $p < 0.05$.

3. Results

No participants were excluded from the study based on anticipation or observation of the contaminant. The proportion of participants who experienced a fall with both arms constrained was significantly higher that the proportion of participants who fell with both arms free (62.5% vs 18.8%; $X^2(1) = 9.14$, $p = 0.01$, Fig. 2). Furthermore, the proportion of participants who fell with the contralateral arm constrained was significantly higher than the proportion of participants who fell with the ipsilateral arm constrained

(68.8% vs 31.2%; $X^2(1) = 3.14$, $p = 0.03$, Fig. 3).

4. Discussion

The purpose of this study was to determine if arm motions assist in the recovery of balance following a slip perturbation. Constraining arm motion had a significant impact on participants' ability to recover from a slip. Specifically, the proportion of participants who fell with the arms constrained was 3 times greater than those who slipped with the arms free. Constraining the arm contralateral to the slipping foot had a larger impact on slip recovery compared to when the ipsilateral arm was constrained. The finding that the incidence of falls in the group with the contralateral arm constrained was similar to the group with both arms constrained leads us to speculate that motion of the contralateral arm is most important in regaining balance from a slip incident. The findings of the current study add to the existing body of knowledge that the upper extremities likely play an essential role in the restoration of balance following an unanticipated perturbation.

Our results are consistent with previous studies that have employed an arm constraint paradigm to study recovery from various balance perturbations. Using a forward-leaning release perturbation, Cheng et al., reported that participants with their arms constrained demonstrated a significantly greater proportions of falls compared to an arms free group (Cheng, Wang, & Kuo, 2015). A similar study using a forward-leaning release perturbation reported that arm responses decreased the trunk angular velocity and provided more time to react and shift the legs into a position to resist a fall (Cheng, Huang, & Kuo, 2014). Using a waist-tug perturbation during treadmill walking, Misiaszek and Krauss reported that individuals with their arms constrained exhibited greater lower extremity neuromuscular responses during the perturbation (Misiaszek & Krauss, 2005).

Previous research has shown that unconstrained arm motions provide a mechanical benefit to regaining balance during a slip. In particular, bilateral flexion responses of the arms have been reported to shift the center of mass anteriorly during a slip (Marigold et al., 2003) as well as reduce the trunk extension velocity in the sagittal plane (Troy et al., 2009). We propose that the greater fall frequency observed in the arms constrained group was due to the inability to initiate an effective alternative means for controlling the center of mass excursion sufficiently to recover balance.

In previous research, the greatest arm excursion during a slip perturbation was observed in the arm contralateral to the slipping foot (Lee-Confer et al., 2022). More specifically, the arm contralateral to the slipping foot exhibited greater excursion in the frontal plane compared to the sagittal plane. Consistent with this finding, constraint of the contralateral arm in the current study resulted is a significantly greater fall frequency than when the ipsilateral arm was constrained. Although the mechanical contributions of the contralateral arm in regaining balance during a slip has not been quantified, it is possible that this arm is responsible for reducing lateral excursion of the body center of mass, similar to what has been reported in moving platform perturbations (Grin et al., 2007).

The findings of the current study have real world implications as individuals naturally constrain their arms while performing everyday tasks. For example, carrying purses, groceries, textbooks, etc. could pose a risk when traversing slippery surfaces (i.e., wet or icy surfaces). Since the arms are important for regaining balance during a slip event, individuals who are at risk for falling (i.e. older adults) should take caution in putting themselves in situations where arm responses could be attenuated. In addition, the results of the current study suggest that the addition of upper extremity strengthening and/or the training of upper extremity reactive responses may be a beneficial addition to fall prevention programs. Evidence in support of the potential benefit of facilitating reactive responses of the arms is provided by the findings of a recent clinical trial that found fall arrest training was superior to standard fall prevention exercises in improving upper body response times in older women (Arnold et al., 2022).

The results of the current study should be viewed in light of certain limitations. First, our study only investigated young, healthy adults. Most serious injuries that result from falls occur in older adults so care should be taken in generalizing these results to this population. Second, all our participants were aware that they would experience a slip a part of this study. Despite our efforts to conceal the trial in which the slip would occur, participants may have adopted a more "protected" gait pattern in anticipation of the slip perturbation, especially during the arm constraint conditions. Such anticipatory behavior could have influenced the proportion of falls observed in each group. Third, kinematic data were not obtained as part of our study. Although an attempt was made to standardize slip perturbations between conditions (ie. walking speed, amount of contaminant, etc.), we cannot exclude the possibility that slip severity (ie. slip distance) was more pronounced when walking with the arms constrained.

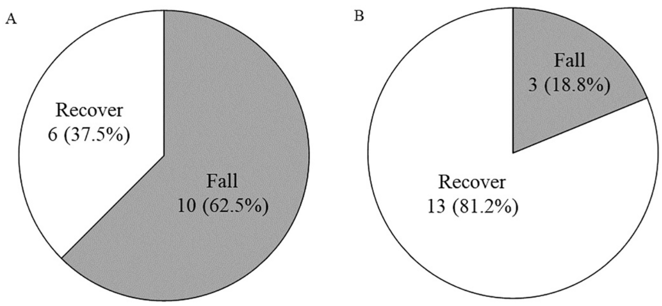

Fig. 2. Fall and recovery frequency of individuals with both arms bound (A) and individuals with their arms free (B). $N = 16$ for each group.

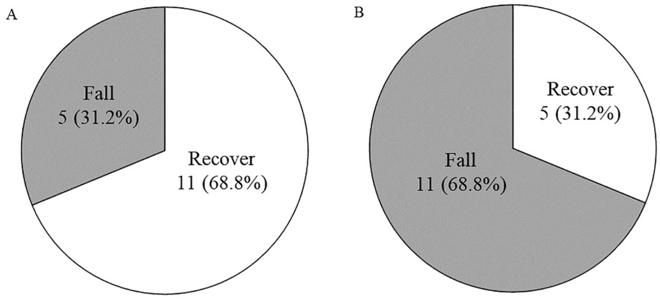

Fig. 3. Fall and recovery frequency of individuals with their ipsilateral arm constrained (A) and individuals with their contralateral arm constrained (B). N = 16 for each group.

5. Conclusion

Results of the current study suggest that the arms are important in regaining balance from a slip perturbation. Specifically, individuals with their arms constrained exhibited a higher proportion of falls compared to the group with the arms free. In addition, individuals assigned to the contralateral arm constraint group exhibited a higher proportion of falls compared to the group in which the ipsilateral arm was constrained. Taken together, our findings suggest that arm motions are important in regaining balance during a slip perturbation, particularly motion of the arm contralateral to the slipping foot.

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Data availability

Data will be made available on request.

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