

Gait adaptations to awareness and experience of a slip when walking on a cross-slope

LAWRENCE, Daniel, DOMONE, Sarah, HELLER, Ben <<http://orcid.org/0000-0003-0805-8170>>, HENDRA, T, MAWSON, Sue and WHEAT, Jonathan <<http://orcid.org/0000-0002-1107-6452>>

Available from Sheffield Hallam University Research Archive (SHURA) at:

<https://shura.shu.ac.uk/11140/>

This document is the Accepted Version [AM]

Citation:

LAWRENCE, Daniel, DOMONE, Sarah, HELLER, Ben, HENDRA, T, MAWSON, Sue and WHEAT, Jonathan (2015). Gait adaptations to awareness and experience of a slip when walking on a cross-slope. *Gait & Posture*, 42 (4), 575-579. [Article]

Copyright and re-use policy

See <http://shura.shu.ac.uk/information.html>

Gait adaptations to awareness and experience of a slip when walking on a cross-slope

Daniel Lawrence ^{a*}, Sarah Domone ^a, Ben Heller ^a, Timothy Hendra ^{a b}, Susan Mawson ^{a c}, Jon Wheat ^a

^a *Sheffield Hallam University, Faculty of Health and Wellbeing, Centre for Sports Engineering Research, Collegiate Hall, Collegiate Campus, Sheffield, S10 2BP, UK*

^b *Royal Chesterfield Hospital NHS Foundation Trust, Chesterfield, UK*

^c *Sheffield University, School of Health and Related Research, Sheffield, UK*

*** Corresponding Author:**

Daniel Lawrence,

Daniel.lawrence2@sth.nhs.uk

+44 07792342817

Sheffield Hallam University,

Faculty of Health and Wellbeing,

Centre for Sports Engineering Research, Collegiate Hall,

Collegiate Campus,

Sheffield, S10 2BP

Gait adaptations to awareness and experience of a slip when walking on a cross-slope

Abstract

Falls that occur as a result of a slip are one of the leading causes of injuries, particularly in the elderly population. Previous studies have focused on slips that occur on a flat surface. Slips on a laterally sloping surface are important and may be related to different mechanisms of balance recovery. This type of slip might result in different gait adaptations to those previously described on a flat surface, but these adaptations have not been investigated. The aim of this study was to assess whether, when walking on a cross-slope, young adults adapted their gait when made aware of a potential slip, and having experienced a slip. Gait parameters were compared for three conditions – 1) Normal walking; 2) Walking after being made aware of a potential slip (participants were told that a slip may occur); 3) Walking after experiencing a slip (Participants had already experienced at least one slip induced using a soapy contaminant). Gait parameters were only analyzed for trials in which there was no slippery contaminant present on the walkway. Stride length and walking velocity were significantly reduced, and stance duration was significantly greater in the awareness and experience conditions compared to normal walking, with no significant differences in any gait parameters between the awareness and experience conditions. In addition, 46.7% of the slip trials resulted in a fall. This is higher than reported for slips induced on a flat surface, suggesting slips on a cross-slope are more hazardous. This would help explain the more cautious gait patterns observed in both the awareness and experience conditions.

Keywords: Slips; Falls; Ageing; Balance; Cross-slope.

1. Introduction

Humans have an inherently unstable posture during gait and are often faced with challenging perturbations due to various environmental factors. Therefore, they are susceptible to falls with

1
2
3
4 potentially serious and sometimes life-threatening consequences [1]. Ageing results in an increased
5
6 susceptibility, potentially leading to functional disability. Even in the absence of injury, a tendency to lose
7
8 balance can result in reduced physical activity and reduced ability to function suitably in social roles [2].
9
10 Several papers have recognised that falls occurring in the community are variable and happen under a
11
12 variety of situations and circumstances. These can include trips, slips, or a change in the support surface,
13
14 for example [3]. Slip-related falls are particularly prevalent, with slips comprising up to 40% of outdoor
15
16 falls in community dwelling older adults [4]. Moreover, up to 25% of fall-related hip fractures result from
17
18 slips [5].
19
20

21
22
23 Maki et al. suggested that medio-lateral balance ability is an important predictor of successful fall
24
25 avoidance [6]. Lateral perturbations during quiet stance have been analysed [2, 6, 7], but understanding of
26
27 a predominantly lateral slip during gait is limited. Several laboratory-based studies have focused on slips
28
29 induced during gait on a flat walkway [8, 9, 10]. Slips have been induced using a sliding platform [10],
30
31 steel rollers [8, 9] or a slippery contaminant [11, 12, 13, 14]. When a slip is induced using a slippery
32
33 contaminant, a medio-lateral component to the slip has been identified even on a flat surface. In
34
35 particular, Troy et al. reported that lateral placement of the recovery foot was an important factor in
36
37 avoiding a fall when stepping onto a flat slippery surface [11]. This supports the notion that maintaining
38
39 lateral balance is an important contributor to avoiding a slip-induced fall. A slip induced on a cross-slope
40
41 is likely to have an increased medio-lateral component, but little is known about the kinematics of
42
43 walking on a potentially slippery cross-slope.
44
45
46
47

48
49 Humans alter their gait patterns when walking on a known slippery surface [15]. For example, when
50
51 walking in simulated slippery conditions on a flat surface, humans often adopt a more “cautious” gait -
52
53 characterized by a shorter step and a flatter foot upon foot strike [16]. Adaptations in gait occur when
54
55 participants are made aware that the surface they are walking on may be slippery. Experience of a slip is
56
57
58
59

not required for adaptations to occur, although prior experience of a slip does cause more pronounced changes in gait than awareness alone [17].

Several investigations of gait adaptations have been performed on a flat walking surface. To our knowledge, gait adaptations on a laterally sloping surface have not been studied. Therefore, the aim of this study was to assess the effect of awareness of potential slips and prior experience of a slip on cross slope walking. It was hypothesized that individuals would adapt their gait with both awareness and experience of a slip, and that adaptations would be more pronounced after experience of a slip.

2. Methods

2.1. Participants

Fifteen men volunteered to participate in the study (age 25.3 ± 2.9 years, height 1.79 ± 0.1 m, mass 72.5 ± 5.6 kg). Participants were healthy with no history of balance or musculoskeletal disorders. All participants read and signed an informed consent form, and all procedures were approved by the Sheffield Hallam University Ethics Committee.

2.2. Experimental setup

Participants wore non-obstructive clothing, and were asked to walk along a purpose built 4.8 m wooden walkway with a cross-slope, inclined by 7° to the horizontal. The incline sloped from the participants' left to right and was covered with a 2.3 m long section of non-slip rubber, followed by a 1.5 m section of vinyl (removable, fixed with Velcro) and, finally, 1 m of non-slip rubber. The full walkway contained both a sloped section and a flat section (Figure 1). This meant that a participant experiencing a large perturbation slipped onto the flat section, rather than off an edge of the walkway, minimizing the risk of injury. Before any walking trials, each participant was fitted into a full body harness, running on an overhead rail - fitted so that each participant had close to full mobility, whilst ensuring their legs would not make contact with the walkway if a fall occurred. Fourteen Polhemus Liberty sensors (Polhemus,

Colchester, VT, USA) mounted on moulded thermoplastic bases, were then attached to body segments using a self-adhesive wrap (Figure 2). Sensors were attached at positions that minimized soft tissue artefact, whilst ensuring motion was not restricted by the sensor wires. The upper trunk sensor was placed on the chest to minimize magnetic interference caused by the metal attachment point on the harness. Subsequently, 35 anatomical landmarks were palpated and digitized using a stylus, with the participant standing in the anatomical position. These landmarks were used to define the proximal and distal endpoints of each body segment, and to define segment anatomical coordinate systems.

2.3.Procedure

All participants completed walking trials, for three different conditions:

- 1) Normal walking (trials 1-5)
- 2) Awareness of a potential slip (trials 6-10)
- 3) Experience of a slip (trials 11-20)

The conditions were presented in the same order for all participants. In condition one, participants completed five walking trials, during which there was no risk of a slip. For conditions two and three, participants were told that there was a possibility of a soapy contaminant being placed on the vinyl section of the walkway. In condition two, no contaminant was actually placed on the walkway, and participants completed five walking trials. In condition three, participants completed 10 trials. During the first trial of condition three (trial 11), the dry vinyl section of the walkway was removed and replaced with an identical vinyl section that was covered with an odourless, transparent and colourless soapy solution (both the sloped and the flat parts of the vinyl section were covered). Following the initial slip trial for condition three, participants completed a further nine trials (trials 12-20) – four with a slippery, and five with a dry, vinyl section. In conditions two and three, participants were distracted between trials (they sat facing away from the walkway, listening to music via headphones), so that they were unaware of

whether the walkway was contaminated. The time between each walking trial was kept as consistent as possible (approximately 2 minutes). During all trials, in all conditions, participants were asked to walk on the sloped part of the walkway as naturally as possible, and to look straight ahead while walking. Room lighting was arranged to ensure that the different reflectivity of the wet surface was not apparent to the participant.

2.4. Data Collection and Analysis

The data for some of the trials were affected by technical problems. However, at least three usable walking trials were available for all participants in each of the conditions. Where more than three usable trials were available, three were randomly selected for analysis. Full body kinematic data were collected using a Polhemus Liberty wired system, sampling data at 240Hz. The data were filtered using a low-pass Butterworth filter (6 Hz cutoff frequency) and further analyzed using Visual 3D (C-motion, Germantown, MD, USA). Foot strike (FS) and Toe Off (TO) events were identified using a kinematic method based on the anterior-posterior velocity of the foot segment relative to the pelvis [18]; FS was defined as the instant of relative positive-to-negative zero crossing of the foot segment velocity, and similarly TO was the negative-to-positive zero crossing. One full gait cycle was analyzed for each trial – foot strike to foot strike of the same foot. The following dependent variables were calculated: a) Stride Length (the anterior-posterior displacement between foot strike of one foot, to foot strike of the same foot; b) Stance Duration (time from foot strike to toe off of the same foot, represented as a percentage of the full gait cycle duration); c) Velocity (stride length * stride frequency); d) Ankle angle at foot strike; e) Step Width (medio-lateral displacement between contralateral footstrikes, along the frontal axis of the laboratory coordinate system). These variables were chosen to ascertain whether participants demonstrate more cautious gait in conditions two and three, as compared to normal walking. A more cautious gait is characterized by slower walking velocity, increased stance duration, and a flatter foot upon foot strike [17].

The stride length and stance duration variables were measured from the first foot strike that occurred on the vinyl section of the walkway. Therefore, the gait cycle that occurred as participants stepped onto the potentially slippery surface was analyzed. The foot that made initial contact with the vinyl surface (i.e. Right or left) was not controlled as participants were asked to walk as naturally as possible. The foot that made initial contact with the vinyl section of the walkway was recorded.

A plantar-dorsiflexion, inversion-eversion, abduction-adduction cardan sequence was used to calculate ankle angle. The plantar-dorsiflexion angle was used for analysis, which was normalised to the position of the foot and shank during the static trial (the ankle angle was zero when participants were in a neutral position).

In all the trials analyzed, there was no slippery contaminant on the surface of the walkway. No kinematic data was analyzed for the slips trials described in the previous section, but the frequency of falls were recorded to provide some context for the gait adaptations. A fall was defined as when both the participants' feet left the ground, and the body was fully suspended in the harness.

2.5. Statistics

Within-subjects repeated measures ANOVA was used to ascertain whether there was a statistical difference for all kinematic parameters across the three conditions. For the gait parameters that were significantly different across the three conditions, a two-tailed paired-samples *t*-test was performed to establish where the differences occurred (Condition 1 vs 2, 1 vs 3, and 2 vs 3). No corrections were made to the data to reduce the likelihood of Type II errors, and to ensure that potentially important differences were not masked [19].

To determine whether there were any differences in the foot which landed first on the vinyl section of the walkway between each condition, a two-tailed binomial test comparing the proportions was used. Statistical significance was set at 0.05 for all analyses.

3. Results

Five of the seven gait variables were significantly different across the three conditions ($P < 0.05$). Only the two step width variables (left FS to right FS and right FS to left FS) showed no significant difference ($P > 0.05$) (Table 1).

The paired-samples *t*-test identified that all pairwise comparisons were significantly different between conditions 1 and 2, and conditions 1 and 3 (Table 2). For condition 2 vs. 3, there were no significant differences for all dependent variables (Table 3).

Stride length decreased by 0.16m and 0.19m respectively in conditions 2 and 3, relative to condition 1. Walking velocity also decreased in conditions 2 and 3, relative to condition 1. The duration of stance phase increased by over 2% in both conditions 2 and 3, compared to condition 1. The ankle angle for both left and right feet was significantly more plantar flexed by 4 - 5° for conditions 2 and 3, relative to condition 1.

The frequency with which the right foot landed on the vinyl section of the walkway increased by 22.1% in both conditions 2 and 3, as compared to condition 1. The binomial test revealed that this increase was significant ($P = 0.034$).

During the slip trials, seven of the participants fell at least once. Of those seven participants, five of them fell more than once.

4. Discussion

The aim of this study was to assess whether young, healthy adults adapt their gait when made aware of a slip, or having experienced a slip when walking on a cross-slope. The analysis revealed that participants adopt a 'cautious' gait, similar to that described by Heiden et al. [17]. When made aware of the risk of a slip, participants adopted a significantly shorter stride, and flatter foot upon foot contact. The same adaptations were observed when participants had experienced a slip, and there were no differences between awareness and experience of a slip. This might suggest that, when given the additional task of negotiating a cross-slope, participants do not need to experience a slip to recognise the threat to their balance.

The stride length results could have been influenced by participants taking a short step immediately before stepping onto the vinyl section. More specifically, several participants lowered their left foot to the ground just before stepping onto the potentially slippery section of the walkway. Therefore, the right foot, which was closest to the flat section of the walkway, would be the first foot to strike the potentially slippery section of the walkway. This strategy would explain the changes observed in the contact foot for the 'awareness' and 'experience' conditions. This behaviour might be explained by balance recovery strategies observed in postural control studies during stance. Research based on lateral perturbations during stance suggest it is more difficult to recover balance, and there is an increased chance of the limbs colliding, when cross-over of the legs is required [20]. In the present study, stepping onto the slippery surface with the right foot may have minimized the possibility of the left foot sliding down the slope, and contacting the right foot when the slip occurred.

The duration of the stance phase (%) increased significantly, and the walking velocity decreased significantly for both the awareness condition and experience condition, compared to normal walking.

1
2
3
4 This again suggests that the perceived risk of falling is high when walking on a potentially slippery cross-
5 slope, regardless of whether or not a slip has been experienced.
6
7
8

9
10 There was no significant effect of walking condition on step width, but for step width from left FS to right
11 FS, the difference was close to significant ($P = 0.053$) - it is possible that a statistical difference may have
12 been identified with a larger sample size.
13
14
15

16
17 The notion that the perceived risk of falling is high when walking on a potentially slippery cross-slope is
18 further supported by the frequency of falls observed. The number of participants that experienced a fall
19 (46.7%) is greater than reported in other studies of slips in young adults [11, 21]. Of the seven
20 participants that fell, five of them experienced more than one fall across the five slip trials. This might be
21 because a slip on cross-slope is less predictable than slips induced using steel rollers or a sliding platform,
22 on a flat surface. The high frequency of falls observed in this in this study is likely explained by the
23 magnitude of the normal force acting on the foot, which is reduced on a slope compared to a flat surface.
24 The reduced normal force requires a higher coefficient of friction to avoid a slip, which makes a slip on a
25 cross-slope more likely than on a flat surface.
26
27
28
29
30
31
32
33
34
35
36
37
38

39 The slips that occur on a contaminant (such as oil or soap) produce a more unpredictable slip compared
40 with those induced using a sliding platform [11, 12, 13, 14, 21]. This type of slip produces some medio-
41 lateral motion of the foot even on a flat surface. This medio-lateral motion is almost completely absent in
42 studies using steel rollers or sliding platforms. Some of these studies using sliding platforms or steel
43 rollers have reported no falls occurring in young adults [9]. It is postulated that the adaptive responses
44 observed in these studies, where there is minimal loss of balance by the fifth slip trial [1], may be because
45 the slips are more predictable, and do not contain a medio-lateral aspect. However, this type of induced
46 balance loss has the advantage of being easier to control.
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4 There were several limitations of the present study that are worth noting. Firstly, a longer walkway may
5
6 have resulted in a more steady-state walking speed, although work conducted by Muir et al. suggests that
7
8 gait is effectively stable within three steps in young adults [22]. Secondly, the use of a harness could
9
10 influence the way that participants walked, in that they knew that the harness would arrest their fall.
11
12 Additionally, one participant grasped the harness during one of the slip trials, which is clearly a reaction
13
14 that cannot be applied to a loss of balance that occurs in the community. Finally, the highly variable
15
16 nature of the slip could be considered a limitation. This could have been somewhat reduced by asking
17
18 participants to contact the potentially slippery section of the walkway with the left or right foot, but this
19
20 ‘targeting’ method could have implications. Studies that have asked participants to contact a force
21
22 platform suggest that, although ‘targeting’ had no effect on ground reaction forces, temperospatial
23
24 alterations were evident in the steps leading up to the target [23]. Therefore, it was decided to avoid
25
26 asking participants to target the vinyl section of the walkway with either the left or right foot.
27
28
29
30
31

32 In summary, participants altered their gait both when aware of a potential slip and having experienced a
33
34 slip, when walking on a cross-slope. A shorter stride length, flatter foot at foot strike, and a slower
35
36 walking velocity are all characteristics of a more cautious gait. There were no significant differences
37
38 between the slip awareness and slip experience conditions. This suggests that, unlike on a flat surface
39
40 [14], there may be an increased perceived risk of falling when walking along a potentially slippery cross-
41
42 slope. This encourages participants to adopt a more cautious gait even without having experienced a slip.
43
44 The higher incidence of falls reported in this study, as compared to previous slips studies, supports the
45
46 notion that perceived risk of falling may explain the more cautious gait patterns observed before a slip has
47
48 occurred. In addition, the high incidence of falls suggests that slips on a cross-slope can be particularly
49
50 hazardous, and potentially present a high risk of injury. Future analysis should focus on how young adults
51
52 recover balance when a slip is induced on a cross-slope, and what differences exist between ‘fallers’ and
53
54 ‘non-fallers’.
55
56
57
58
59
60
61
62
63
64
65

Acknowledgements

The study was funded by a Sheffield Hallam University Studentship

References

- [1] Bhatt T, Wening JD, Pai Y-C. Adaptive control of gait stability in reducing backward loss of balance. *Exp Brain Res* 2006;170:61-73.
- [2] Rogers MW, Mille M-L. Lateral stability and falls in older people. *Exercise Sport Sci R* 2003;31:182-87.
- [3] Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing* 1997;26:261-68.
- [4] Luukinen H, Herala M, Koski K, Honkanen R, Laippala P, Kivelä SL. Fracture risk associated with a fall according to type of fall among the elderly. *Osteoporosis Int* 2000;11:631-34.
- [5] Nyberg L, Gustafson Y, Berggren D, Brännström B, Bucht G. Falls leading to femoral neck fractures in lucid older people. *J Am Geriatr Soc* 1996;44:156-60.
- [6] Maki BE, McIlroy WE. Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention. *Age and Ageing* 2000;35:ii12-ii18.
- [7] Maki BE, Edmondstone MA, McIlroy WE. Age-related differences in laterally directed compensatory stepping behavior. *J Gerontol A Biol Sci Med Sci* 2000;55:M270-77.
- [8] Marigold DS, Patla AE. Strategies for dynamic stability during locomotion on a slippery surface: effects of prior experience and knowledge. *J Neurophysiol* 2002;88:339-53.

- [9] Marigold DS, Bethune AJ, Patla AE. Role of the unperturbed limb and arms in the reactive recovery response to an unexpected slip during locomotion. *J Neurophysiol* 2003;89:1727-37.
- [10] Bhatt T, Wening JD, Pai Y-C. Influence of gait speed on stability: recovery from anterior slips and compensatory stepping. *Gait Posture* 2005;21:146-56.
- [11] Troy KL, Donovan SJ, Marone JM, Bareither ML, Grabiner MD. Modifiable performance domain risk-factors associated with slip-related falls. *Gait Posture*, 2008;28:461-5.
- [12] Cham R, Redfern MS. Lower extremity corrective reactions to slip events. *J Biomech* 2001;34:1439-1445.
- [13] Lockhart TE, Smith JL, Woldstad JC. Effects of Aging on the biomechanics of slips and falls. *Hum Factors* 2005;47:708-729.
- [14] Brady RA., Pavol MJ, Owings TM, Grabiner MD. Foot displacement but not velocity predicts the outcome of a slip induced in young subjects while walking. *J Biomech* 2000; 33 (7): 803-808.
- [15] Cham R, Redfern MS. Changes in gait when anticipating slippery floors. *Gait Posture* 2002; 15(2): 159-71
- [16] Moyer BE, Chambers AJ, Redfern MS, Cham, R. Gait parameters as predictors for slip severity in younger and older adults. *Ergonomics* 2006;49:329-43.
- [17] Heiden TL, Sanderson DJ, Inglis JT, Siegmund GP. Adaptations to normal human gait on potentially slippery surfaces: The effects of awareness and prior slip experience. *Gait Posture* 2006;24:237-4.

- 1
2
3
4 [18] Zeni JA Jr, Richards JG, Higginson JS. Two simple methods for determining gait events during
5 treadmill and overground walking using kinematic data. *Gait Posture* 2008;27:710-714.
6
7
8
9
10 [19] Perneger TV. What's wrong with Bonferroni adjustments. *Brit Med J* 1998;316:1236-8.
11
12
13 [20] Mille ML, Johnson ME, Martinez KM, Rogers MW. Age-dependent differences in lateral balance
14 recovery through protective stepping. *Clin Biomech* 2005;20: 607–16.
15
16
17
18 [21] Troy KL, Grabiner MD. Recovery responses to surrogate slipping tasks differ from responses to
19 actual slips. *Gait Posture* 2006;24:441-47.
20
21
22
23
24 [22] Muir BC, Rietdyk S, Haddad JM. Gait initiation: The first four steps in adults aged 20–25 years, 65–
25 79 years, and 80–91 years. *Gait Posture* 2014;39:490-94.
26
27
28
29
30 [23] Wearing SC, Urry, SR, Smeathers, JE. The effect of visual targeting on ground reaction force and
31 temporospatial parameters of gait. *Clin Biomech* 2000;15:583-591.
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Table 1 – Summary of results from the Repeated Measures ANOVA analysis. Results are presented as

Dependent Variables	Normal Walking	Slip Awareness	Slip Experience	P Value
Stride length (m)	1.42 ± 0.11	1.26 ± 0.16	1.23 ± 0.16	0.000*
Stance duration (%)	61.2 ± 1.4	63.9 ± 2.9	63.9 ± 2.3	0.000*
Velocity (m/s)	1.25 ± 0.13	1.07 ± 0.25	1.05 ± 0.18	0.006*
Left ankle angle (°)	1.1 ± 6.2	5.3 ± 5.2	6.1 ± 6.9	0.004*
Right ankle angle (°)	-1.7 ± 4.3	2.8 ± 6.6	3.2 ± 10.8	0.031*
Step width - right FS to left FS (m)	0.15 ± 0.5	0.16 ± 0.5	0.16 ± 0.5	0.162
Step width - left FS to right FS (m)	0.8 ± 0.4	0.10 ± 0.3	0.10 ± 0.3	0.053

mean ± standard deviation

* Indicates a Significant difference at $P \leq 0.05$ level

Table 2. Paired Sample T-test comparisons of gait parameters for normal walking vs awareness and experience of a slip

Variable	Condition	Mean Difference	Sig (vs. Normal)
Stride Length (m)	Normal Walking		
	Awareness	-0.16	0.001*
	Experience	-0.19	0.001*
Duration of Stance (%)	Normal Walking		
	Awareness	2.7	0.003*
	Experience	2.7	0.000*
Velocity (m/s)	Normal Walking		
	Awareness	-0.18	0.023*
	Experience	-0.20	0.002*
Right ankle angle at foot strike (°)	Normal Walking		
	Awareness	4.5	0.002*
	Experience	4.9	0.047*
Left ankle angle at foot strike (°)	Normal Walking		
	Awareness	4.2	0.001*
	Experience	5.0	0.010*

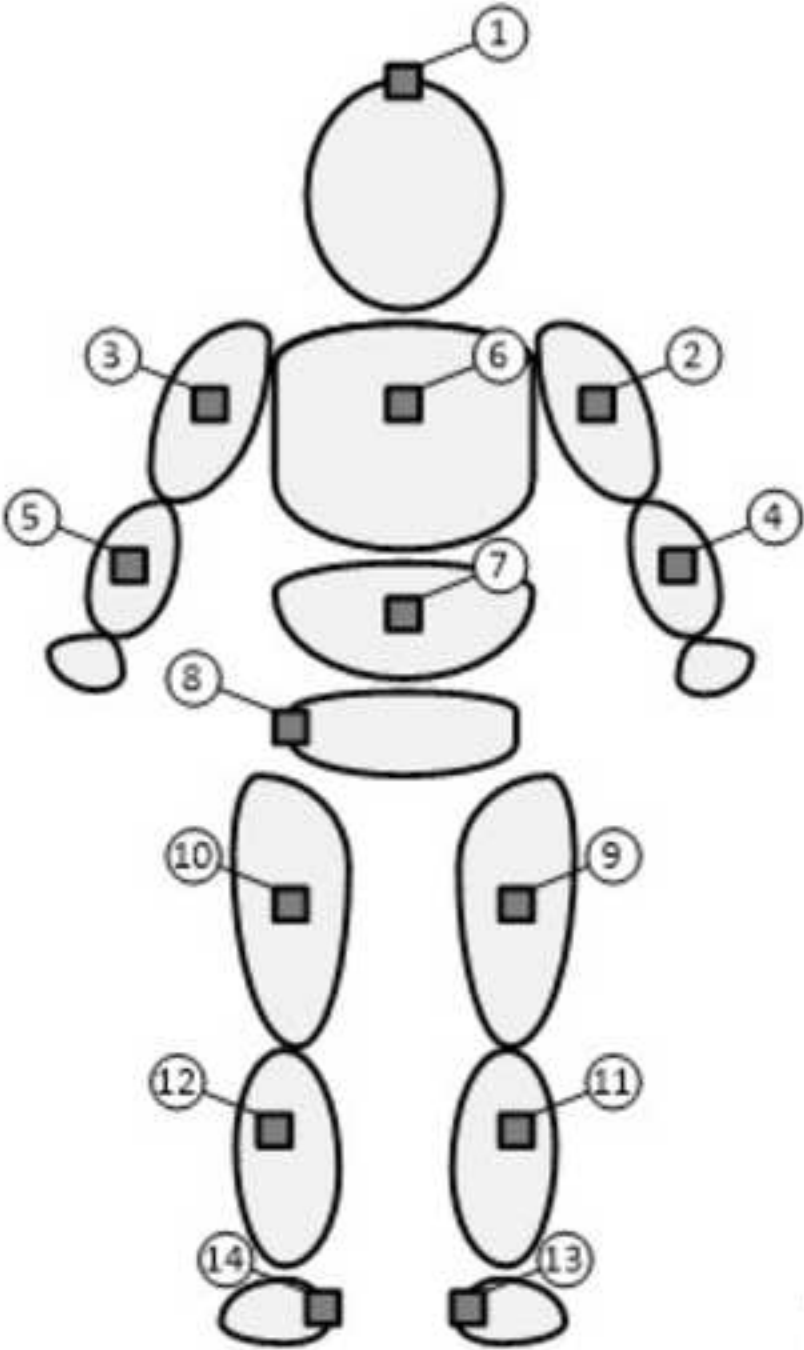
*Indicates a Significant difference at $P \leq 0.05$ level

Table 3. Paired Sample t-test comparisons of gait parameters for awareness vs experience of a slip

Variable	Condition	Mean Difference	Sig.
Stride Length (m)	Awareness		
	Experience	0.03	0.194
Duration of Stance (%)	Awareness		
	Experience	0.0	0.919
Velocity (m/s)	Awareness		
	Experience	0.02	0.561
Right ankle angle at foot strike (°)	Awareness		
	Experience	-0.4	0.779
Left ankle angle at foot strike (°)	Awareness		
	Experience	-0.8	0.592

*Indicates a Significant difference at $P \leq 0.05$ level

7. Figure 2
[Click here to download high resolution image](#)



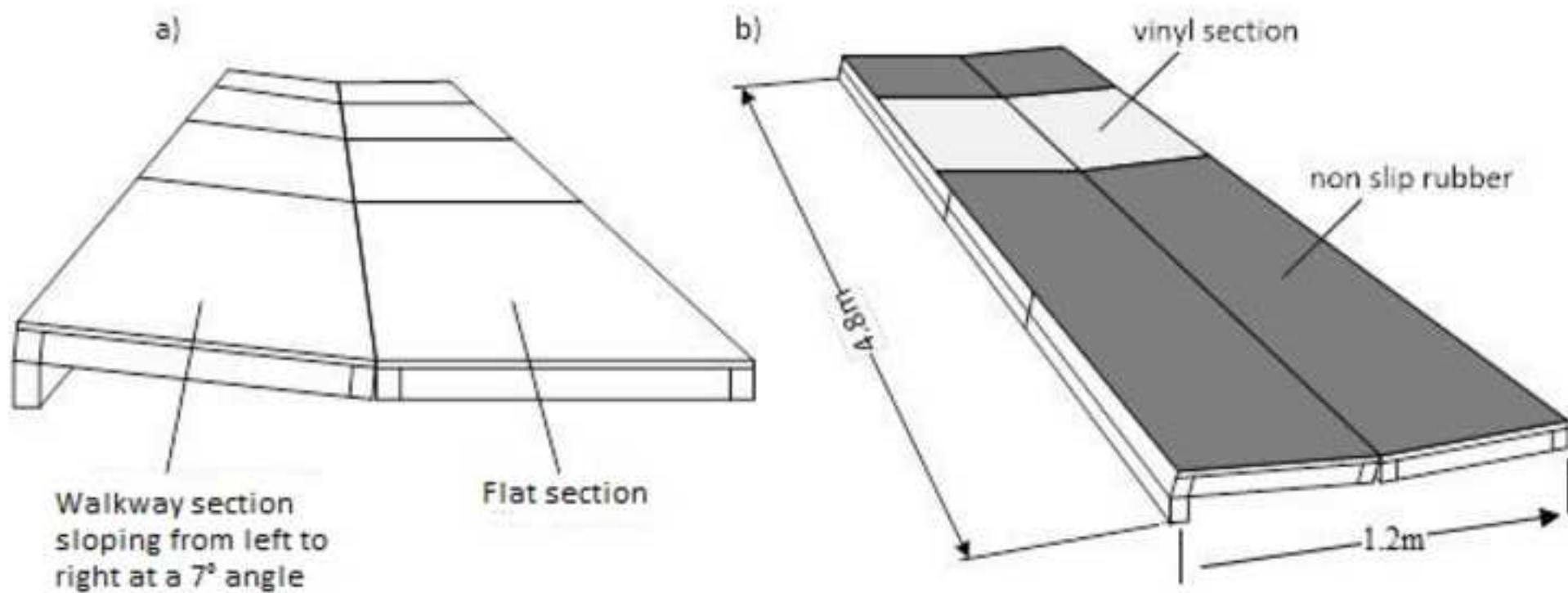
Sensor No.	Segment
1	Head
2	Left upper arm
3	Right upper arm
4	Left forearm
5	Right forearm
6	Upper trunk
7	Lower trunk
8	Pelvis
9	Left thigh
10	Right thigh
11	Left shank
12	Right shank
13	Left foot
14	Right foot

7. Figure 1 and 2 captions

Figure 1 - Cross slope set up, a) wooden frame of the cross slope illustrating flat section and angled section, b) walkway covered in non-slip rubber and a 1.5m section of vinyl

Figure 2 - Schematic of position of Polhemus sensors on individual body segments

7. Figure 1
[Click here to download high resolution image](#)



Research Highlights

- First slips study to conduct analysis on a cross-slope
- Cautious gait patterns observed when aware that a slip might occur on a cross-slope
- Cautious gait patterns also observed after experiencing a slip on a cross-slope
- No differences between potential awareness and experience of a slip
- High incidence of falls when participants slip on a cross-slope