

Kinematic differences exist between transtibial amputee fallers and non-fallers during downwards step transitioning

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Abstract

Study Design: Cross-sectional study.

Background: Stair negotiation is biomechanically more challenging than level gait.

There are few biomechanical assessments of transtibial amputees descending stairs and none specifically related to falls. Stair descent may elicit more differences than level gait in amputees with and without a previous falls history.

Objectives: The aim of this study was to compare the gait kinematics of fallers and non-fallers during downwards step transitioning in transtibial amputees.

Methods: Six fallers and five non-fallers completed step transition trials on a three-step staircase at their self-selected pace.

Results: Nine participants exhibited a clear preference to lead with the affected limb, while two had no preference. Four participants self-selected a step-to rather than a reciprocal stair descent strategy. The fallers who used a reciprocal strategy walked 44% more quickly than the non-fallers. To compensate for the lack of active plantar flexion of the prosthetic foot, exaggerated range of motion occurred proximally at the pelvis during swing. The step-to group was more reliant on the handrails than the reciprocal group and walked more slowly.

Conclusions: As anticipated, the fallers walked faster than the non-fallers despite employing the more difficult 'roll-over' technique. Handrail use could help to improve dynamic control during downwards step transitions.

Word count: 203

2 **Clinical relevance**

3 Transtibial amputees are advised to descend steps using external support, such as
4 handrails, for enhanced dynamic control. Hip abductor and knee extensor eccentric
5 strength should be improved through targeted exercise. Prosthetic socket fit should be
6 checked to allow adequate knee range of motion on the affected side.

7

8 **Word count: 47**

9 **Background**

10 Like stair ascent, walking down stairs involves the rhythmic shift of body weight in the
11 vertical and horizontal directions. Stair descent is characterised by eccentric forces
12 from the ankle plantar flexors and knee extensors during the weight acceptance
13 (loading) and controlled lowering (pre-swing) phases⁽¹⁻²⁾. The controlled lowering phase
14 is accomplished through large eccentric muscle forces, particularly about the knee, and
15 corresponds to a phase in the gait cycle when failure could result in a fall⁽³⁾. Falls that
16 occur during stair negotiation are more likely to happen during stair descent than
17 ascent and the consequences are often more severe^(4,5). Difficulties descending stairs
18 have been linked with poor balance and gait abnormalities in non-disabled older
19 adults⁽⁶⁾. Reeves et al. (2008a) have shown that older adults function close to their
20 biomechanical limits during stair descent⁽⁴⁾.

21

22 Compared to able-bodied individuals, transtibial amputees exhibit altered lower limb
23 mechanics as a result of reduced joint mobility, muscle weakness, postural instability⁽⁷⁾
24 and gait modifications that predispose them to falling⁽⁸⁾. Previous research found that
25 52% of lower limb amputees fall annually and that 75% are recurrent fallers⁽⁹⁾. These
26 numbers are significantly higher than among age-matched, able-bodied individuals.
27 Moreover, these values may be underestimated as not all falls are reported.

28

29 There are few studies that have conducted biomechanical investigations of transtibial
30 amputees transitioning downwards on steps and the mechanical adaptations they

31 make during this complex task are not as well understood. Previous reports
32 demonstrated that transtibial amputees maintain the knee extended on the affected
33 side for a longer period of time to compensate for the loss of the dorsiflexor and plantar
34 flexor muscle groups during stair descent^(10,11). They also noted that the amputees 'fall'
35 onto the intact leg, which was considered a compensatory movement related to the
36 excessive loading at the ankle and knee joints of this limb⁽¹⁰⁾.

37

38 There is a paucity of research into downwards step transitioning in transtibial amputees
39 and specifically in relation to falls. Such evidence-based findings would have important
40 implications for rehabilitation programmes by making recommendations for targeted
41 exercises to improve musculoskeletal function. The aim of this study was to compare
42 the gait kinematics of transtibial amputee fallers and non-fallers transitioning
43 downwards on steps. We predicted that amputee fallers would step downwards more
44 quickly than the non-fallers. This was based on our previous observations that the
45 fallers walked more quickly over level ground and during stair ascent^(8, 12). It was also
46 anticipated the fallers would exhibit increased joint mobility, compared to the non-fallers
47 and that this would be especially evident at the lower limb joints on the affected side.
48 This was expected because the fallers demonstrated greater joint range of motion
49 (ROM) on the affected side during stair ascent⁽¹²⁾.

50 **Methods**

51 ***Participants***

52 Eleven transtibial amputees were recruited from the local Artificial Limb Unit (Table 1).
53 Participant inclusion criteria specified participants must have worn their prosthesis on a
54 daily basis without experiencing pain; and were able to ascend and descend a three-
55 step staircase independently without walking aids, although the use of handrails was
56 permitted. Participants were classified as either fallers (n=6) or non-fallers (n=5) based
57 on their falls history in the 9-month period leading up to testing. As described
58 previously⁽¹²⁾, one participant fell during stair descent specifically, two participants fell
59 during stair ascent, and three fell during level and/or slope walking in the 9-month
60 period preceding testing. Moreover, no significant differences were found between the
61 two groups for physical characteristics as reported in our earlier studies^(8,12). The
62 current study was approved by the NHS Local Research Ethics Committee (REC
63 number: 05/Q1105/68). All participants gave written informed consent to take part in
64 this research.

65

66 ***Staircase***

67 A three-step wooden staircase was built for this study. The steps were 80 cm wide,
68 with a rise of 20 cm, a tread of 25 cm, and a final tread of 80 cm. These dimensions
69 conformed to Building Regulations 2010 for England. Wooden handrails were 50 cm
70 high and attached to the main structure⁽¹²⁾ (Figure 1).

71

72 **Protocol**

73 Three-dimensional kinematic data were obtained from ten ProReflex MCU1000
74 cameras sampling at 100 Hz using Qualisys Track Manager software (Qualisys,
75 Sweden). The calibration details have been reported previously⁽¹²⁾. All participants
76 completed the test wearing their own comfortable walking shoes. A six-degrees-of-
77 freedom marker set-up for static and dynamic trials was used^(8, 12). Participants first
78 climbed the three-step staircase at their own pace. After turning around and a self-
79 selected rest period on the top landing, participants took up to two steps on the landing
80 before descending the three steps and kinematic data were captured for a total of 12
81 trials involving downwards step transitions at the top and bottom of the staircase.

82

83 **Data analysis**

84 Kinematic data were processed and analysed as before⁽⁸⁾ and normalised to the gait
85 cycle starting with toe-off⁽¹⁾. As participants were instructed to descend the steps
86 naturally, the data were first inspected to determine their lead limb preference. This
87 revealed that 9 of 11 participants displayed a preference for leading with the affected
88 limb, while two had no clear limb preference. Therefore the affected limb was selected
89 as the lead limb for all participants. With a reciprocal strategy and descending two
90 vertical step heights, the affected (lead) limb transitioned from the first step to the floor;
91 the unaffected (trail) limb transitioned from the top landing to the second step. As the
92 gait cycle was initiated and terminated with toe-off⁽¹⁾, the stance phase for the affected
93 limb occurred on the floor. Two fallers and two non-fallers used a 'step-to' strategy

94 meaning that they descended one step at a time. Under these circumstances, the total
95 vertical distance covered by each limb was only one step (Table 1). Thus, the gait cycle
96 from the first to the second step was analysed for the step-to participants. Given that
97 the participants displayed rather unique stair descent strategies, each group was
98 separated into those who used reciprocal vs. step-to descent strategies and group
99 numbers were reduced. Thus, it was not deemed appropriate to conduct statistical
100 analysis as the sample size was reduced. The following results sections use
101 descriptive statistics to compare the groups according to falls history and strategy.
102

103 ***Variables***

104 The gait variables that were selected for analysis included 1) temporal-spatial
105 parameters: average resultant walking speed (m/s) and support times (as % of gait
106 cycle); along with 2) joint kinematics at specific time points (°) and ROM across the full
107 gait cycle for the hip, knee and ankle bilaterally. Data were analysed in the sagittal
108 plane, but hip and pelvic kinematics were also analysed in the frontal plane.
109

110 **Results**

111 The data are presented for fallers vs. non-fallers who used a reciprocal and step-to
112 downwards step transition strategy according to affected (lead) and intact (trail) limbs.
113

114 ***Temporal-spatial variables***

115 Of the participants using a reciprocal strategy, the fallers walked 44% more quickly
116 compared to the non-fallers. There were no meaningful differences between fallers vs.
117 non-fallers for stance phase duration.

118

119 The step-to groups were markedly slower overall, with the fallers walking 29% more
120 slowly compared to the non-fallers. The step-to fallers walked 66% more slowly than
121 the fallers who used a reciprocal strategy. The step-to fallers also exhibited a 15%
122 longer affected stance phase and 5% longer intact stance phase compared to the non-
123 fallers (Table 2).

124

125 ***Sagittal and frontal kinematic variables – Reciprocal downwards step transition***
126 ***strategy***

127 Peak sagittal and frontal plane joint and pelvic kinematics are presented in Tables 2
128 and 3 and illustrated in Figures 2 and 3, respectively.

129

130 Notable differences were found for peak hip extension during late stance (pre-swing)
131 on the affected side when the foot was on the floor. While the fallers displayed full hip
132 extension ($0.7 \pm 2.9^\circ$), the non-fallers showed almost 20° of flexion (Table 2). The hip on
133 the affected side revealed almost 61% greater ROM in the fallers compared to the non-
134 fallers.

135 Less obvious kinematic differences were found at the knee joint. The fallers displayed
136 less knee flexion at foot contact on the affected side compared to the non-fallers.
137 Overall knee ROM was not too dissimilar across both groups and between limbs.

138

139 Compared to the non-fallers, the fallers exhibited more ankle dorsiflexion (7.6°) at toe-
140 off on the intact side (Table 2). As expected, a between-limb difference occurred at the
141 ankle joint where the prosthetic ROM remained in dorsiflexion and was almost a
142 quarter of that observed on the intact side. On the affected side, foot contact occurred
143 with the ankle almost neutral whereas on the intact side, the ankle was plantar flexed at
144 approximately 20° and 18° (fallers and non-fallers, respectively).

145

146 Peak anterior pelvic tilt tended to occur during mid-swing. The fallers exhibited on
147 average at least 5° less anterior pelvic tilt compared to the non-fallers (Figure 2).

148

149 Participants displayed minimal hip adduction at toe-off, followed by increasing hip
150 abduction of the affected limb during swing in preparation for foot placement. The most
151 noteworthy difference occurred during mid-stance, where the fallers exhibited a neutral
152 angle on average, whereas the non-fallers exhibited 5° more hip adduction on the
153 affected side (Table 3, Figure 3).

154

155 Both groups showed very similar frontal plane pelvic ROM and initiated toe-off with the
156 pelvis up (pelvic hike). From toe-off through swing, pelvic hike changed to pelvic drop
157 as the swing leg was preparing to make foot contact with the step below (Figure 3).

158

159 ***Sagittal and frontal kinematic variables – Step-to downwards step transition***
160 ***strategy***

161 The step-to fallers maintained the hip approximately 20° and 17° more flexed on the
162 affected and intact sides, respectively, during stance compared to the reciprocal group
163 (Table 2). They also had a smaller hip ROM ($31.7\pm 3.0^\circ$) compared to the fallers with a
164 reciprocal strategy ($50.2\pm 9.1^\circ$).

165

166 The most noteworthy difference at the knee joint was that the fallers maintained the
167 knee on the affected side less flexed at toe-off and during swing and exhibited almost
168 19° reduced ROM compared to the non-fallers (Table 2). Moreover, ROM on the
169 affected side was less than half the ROM for the fallers using a reciprocal strategy.

170

171 For both step-to groups, the intact ankle remained dorsiflexed throughout the entire gait
172 cycle and was dorsiflexed greatly (over 40°) for the non-fallers during late stance
173 (Table 2).

174

175 Hip adduction profiles were varied with little difference between the fallers and non-
176 fallers. The hip was abducted on the affected side in swing. For both groups, hip ROM

177 in the frontal plane was larger on the affected side compared to the intact side (Table
178 3). Pelvic obliquity was very similar.

179

180 **Discussion**

181 The aim of this study was to contrast the gait patterns of fallers and non-fallers during
182 downwards step transitioning, as multiple stair descent cycles could not be achieved
183 with a three-step staircase. All of the participants were able to complete the task
184 successfully, although four amputees (2 fallers and 2 non-fallers) self-selected a step-
185 to rather than a reciprocal stair strategy.

186

187 ***Reciprocal downwards step transition strategy group***

188 ***Temporal-spatial***

189 Our predictions related to walking speed and the results indicated that walking speed
190 was reduced during downwards step transitioning, supporting the notion that it was a
191 more mechanically complex task than level walking⁽⁸⁾ and similar to stair ascent⁽¹²⁾. As
192 walking speed is considered a good indicator of physical mobility, the mechanical
193 challenge of descending steps is emphasised by a slowing down⁽¹³⁾.

194

195 Few published studies report speed during stair descent in lower limb amputees.
196 Torburn et al. reported that transtibial amputees descended stairs at a rate of 1.6
197 stairs/s⁽¹⁴⁾. Powers et al. (1997) and Ramstrand et al. (2009) reported average
198 velocities of 29.6 m/min (0.49 m/s)⁽¹³⁾ and 0.48 m/s⁽¹⁵⁾, respectively, for their transtibial

199 amputees. More recently, Wolf et al. (2012) reported stair descent speeds of 0.42 and
200 0.45 m/s for transfemoral amputees using a Power Knee and C-Leg, respectively⁽¹⁶⁾. In
201 the current study, the amputee fallers walked more than 0.2 m/s faster than these
202 previous studies^(13, 15), whereas the non-fallers' speeds were virtually the same as
203 reported for other transtibial amputees^(13, 15).

204

205 In accordance with our expectations, the fallers descended more quickly than the non-
206 fallers. The current findings suggest the fallers may have put themselves at risk for
207 falling by descending at higher speeds. Walking speed has been used as an overall
208 indicator of function⁽¹⁷⁾. Descending more quickly may imply higher functioning, as
209 faster speeds often require sufficient joint ROM and eccentric muscle strength.

210 However, in the absence of adequate lower limb musculoskeletal strength and
211 flexibility, an amputee may in fact be placing themselves at risk of a prospective fall. It
212 is surprising that the fallers descended steps at speeds faster than those reported for
213 other transtibial amputees given that some of their previous falls in the 9-month period
214 before testing actually occurred during stair negotiation. It is possible that the fallers
215 had high self-efficacy beliefs and perceived their locomotor ability to be sufficient to
216 ambulate quickly under familiar circumstances, such as descending a short staircase.
217 Consequently they evaluated this task as relatively low-risk. Conversely, the weaker or
218 more cautious amputees were likely to have altered perceptions of risk and negotiated
219 uncertain situations more slowly in an attempt to avoid a fall. Thus fear of falling is an
220 important consideration when addressing falls-related issues. It is possible the non-

221 fallers were actually more fearful of a prospective fall than the previous fallers, as fear
222 of falling has been associated with slower speeds⁽¹⁸⁾. Moreover, 2 of the 5 non-fallers
223 were women, which may have influenced fear of falling, as women report greater fear
224 than men⁽¹⁹⁾. Future work investigating biomechanical differences in fallers vs. non-
225 fallers should include information about participants' fear of falling to provide a more
226 holistic overview.

227

228 One strategy for improved dynamic stability during stair negotiation is handrail use, as
229 has been advocated in other stair studies with older (able-bodied) adults⁽²⁰⁾. Reeves et
230 al. (2008b) demonstrated that handrail use could redistribute some of the work onto the
231 arms and partially unload the legs, thereby reducing the demands on the knee
232 extensors⁽²⁰⁾. In the current study, the fallers only used the handrails 'lightly', as a guide
233 for one hand. Given their faster walking speed, using the handrail on both sides (if
234 available) would enhance dynamic control of balance on the affected and intact sides.
235 Handrail use would also benefit amputees using the more complex 'roll-over'
236 technique. This technique involves placing the midfoot over the nose of the step and
237 rolling over the edge while in single support (also known as controlled lowering). It is
238 useful with reduced joint mobility at the ankle and knee on the affected side. In this
239 study, the fallers tended to use a 'roll-over' technique, similar to that reported in
240 transfemoral amputees⁽¹⁰⁾. In any case, we advocate handrail use at all times for better
241 dynamic control.

242 ***Joint kinematics***

243 We predicted that joint mobility reflected in the lower limb joint angles at specific
244 instances and overall ROM would be different between the fallers and non-fallers for
245 the affected limb. The ankle joint plays a crucial role during weight acceptance,
246 demanding eccentric control by the ankle plantar flexors when initial contact is made,
247 typically with the forefoot. Ankle plantar flexion assists in lengthening the leg in
248 preparation for contact with the step below. This facilitates smoother movement of the
249 CoM in the vertical and horizontal directions. In the absence of active plantar flexion
250 with the prosthetic foot, compensations are likely to occur proximally at the hip and
251 pelvis. Previous studies investigating stair descent in amputees have not specifically
252 examined pelvic hike or drop^(10, 11, 13, 14). In the current study, both fallers and non-fallers
253 showed exaggerated pelvic ROM in the frontal plane when compared to young and
254 older able-bodied adults completing the same task⁽²¹⁾. Increased frontal plane hip and
255 pelvic motion has been related to lack of neuromuscular control in able-bodied older
256 adults and weakness in the hip abductor musculature. A large internal hip abductor
257 moment is required to control the amount of hip adduction in late stance⁽²¹⁾. Increased
258 frontal plane motion around the hip suggests proximal compensations were not solely
259 due to insufficiencies of the prosthetic foot and ankle, but also muscle weakness
260 around the hip. Therefore, increased strength of the hip abductors could also help to
261 improve dynamic control when descending steps.

262

263 Peak ankle joint kinematics were similar to those reported by Powers et al. (1997) for
264 transtibial amputees⁽¹³⁾. Peak dorsiflexion in stance was limited by the prosthetic ankle.
265 Knee flexion could have been inhibited as socket fit tends to be high posteriorly⁽²²⁾. The
266 non-fallers showed a tendency to 'throw' their prosthetic foot down onto the next step
267 compared to the fallers. This was evident with more hip flexion at toe-off and
268 throughout swing, thus lifting the whole leg into the air for stair clearance. Similar
269 observations were reported in transtibial amputees when crossing obstacles with their
270 prosthesis as the lead limb⁽²²⁾.

271

272 At the knee, the only noteworthy kinematic difference between the groups was smaller
273 knee range of motion on the affected side in the non-fallers ($78.8 \pm 4.1^\circ$) compared to
274 the fallers ($86.9 \pm 7.5^\circ$). This reflected a combination of greater knee flexion at initial
275 contact (because the limb was being 'thrown' over the step) and possibly differences in
276 prosthetic socket fit restricting peak flexion.

277

278 There were larger differences when hip kinematics were examined. The hip joint on the
279 affected side was fully extended in stance ($-0.7 \pm 2.9^\circ$) for the fallers and displayed
280 larger range of motion compared to the non-fallers. This was related to the fact that the
281 affected limb was measured from the first (middle) step to the floor. Initiating and
282 terminating the gait cycle with toe-off meant that the stance phase of the affected limb
283 was analysed when the foot was already on the ground and about to start level
284 walking. Peak hip extension has been linked with walking speed, with greater hip

285 extension observed at faster speeds⁽²³⁾. As the fallers stepped more quickly downwards
286 and also during level walking⁽⁸⁾, it is likely they would have extended their hip more in
287 pre-swing prior to toe-off.

288

289 ***Step-to group***

290 To date, no studies have revealed a step-to gait strategy in lower limb amputees
291 descending stairs. Our previous work has shown that this strategy is not unique to stair
292 descent, as two of the same participants who used a step-to strategy during descent
293 also exhibited the same strategies during ascent⁽¹²⁾. The step-to groups most likely
294 adopted this gait strategy because of functional and strength limitations at the knee of
295 both limbs. The time spent in single support on the affected limb was reduced and the
296 knee was maintained almost completely extended. The controlled lowering phase, the
297 most vulnerable phase during stair descent, was substantially shorter for the intact
298 (trail) limb and virtually absent for the affected (lead) limb as the knee was maintained
299 in an extended position.

300

301 In this study, 9 out of 11 amputees led with their affected limb on all occasions, while 2
302 participants showed no clear preference. It is plausible that the reduced space on the
303 top landing, which limited the number of steps that could be taken prior to descending,
304 prompted participants to lead with their affected limb. This may have introduced a limb
305 preference bias. However, transtibial amputees frequently are taught to lead with their
306 prosthesis/affected limb during stair descent, and so we believe the limb preference

307 was representative of typical stair walking. This is because the trail limb must flex at the
308 knee to ensure safe lowering during the controlled lowering phase (lead limb swing
309 phase, trail limb single support phase) and move through a greater knee ROM.

310 Depending on prosthetic fit, the height of the prosthetic socket behind the knee could
311 limit joint flexion. Though modifiable, if prosthetic socket fit was limiting knee ROM,
312 particularly flexion, then that could have had a detrimental effect on stair locomotion.

313

314 The main distinguishing characteristics between the fallers and non-fallers was
315 reduced ROM at the ankle and knee joints. Although reduced joint mobility was a
316 characteristic of the step-to gait strategy, a certain range of motion would still be
317 necessary to negotiate stair descent and transition downwards on steps safely. The
318 inability to achieve this may be considered a risk factor for falling. Exercise
319 programmes aimed at improving knee extensor eccentric strength and knee joint
320 mobility on the affected side, in those individuals adopting the step-to gait strategy,
321 would be encouraged.

322

323 Some limitations of this study must be acknowledged. By using a three-step staircase,
324 as has been done previously⁽²⁴⁾, the gait cycle inevitably involves a component of level
325 walking, and thus represents more of a step transition. However, this is representative
326 of real-life and the transition from steps to level walking warrants study as it may
327 present an increased falls risk compared to level or continuous stair walking⁽²⁵⁾. As the
328 participants chose to lead with their affected limb, it meant this limb was the first to

329 reach the ground. We did not deem it safe enough to ask participants to lead with their
330 intact limb expressly, given their affected limb preference and falls history on stairs.
331 Thus, no true controlled lowering phase on the affected side could be analysed.
332 Although speed has been shown to influence kinematic parameters, such as ROM and
333 peak joint angles⁽²³⁾ it was not controlled for in this study. This was to allow participants
334 to descend stairs using their most natural gait pattern, but also to ensure their safety
335 during a more complex task. The small participant numbers also make it difficult to
336 generalise the findings to the wider amputee population, whilst the reduced sample
337 size made statistical analyses problematic. Achieving adequate participant numbers,
338 whilst accounting for the variability that amputee fallers and non-fallers can present
339 with, is a complex task. Finally, it was not possible to differentiate between cause and
340 effect, and it remains unclear whether the fallers' gait patterns contributed to their falls
341 history, or whether the consequence of falling resulted in modified gait patterns.

342

343 **Conclusion**

344 This biomechanical analysis in amputee fallers vs. non-fallers provided some initial
345 evidence that these two groups adopted different strategies during downwards step
346 transitioning. In agreement with our predictions, the fallers walked faster than the non-
347 fallers and exhibited larger ROM in the lower limb joints on the affected leg in the
348 reciprocal groups. Notably, the non-fallers appeared to 'throw' their prosthesis over the
349 edge of the step, whilst the fallers employed the more difficult 'roll-over' technique,
350 requiring adequate strength and control of the knee extensor musculature. More

351 participants adopted a step-to gait strategy in stair descent than ascent and this
352 reduced the demands on joint mobility and muscle strength. The vulnerable controlled
353 lowering phase was missing on the affected limb for the step-to group.

354

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Table 1: Mean (SD) participant characteristics and stair descent strategies.

Participant	Gender	Age (yrs)	Height (cm)	Mass (kg)	Time since amputation (yrs)	Residual stump length (cm)	Prosthetic foot	Cause of amputation	Lead limb preference	Handrail use	Stair descent strategy
Fallers											
1	M	46	181	83	12.0	13.0	Variflex	Traumatic	Affected	Light	Reciprocal
2	M	43	173	76	1.2	15.0	Ceterus	Traumatic	Affected	Light	Reciprocal
3	M	67	168	62	1.7	23.0	Multiflex	Traumatic	Affected	Light	Reciprocal
4	M	43	196	93	4.0	19.5	Multiflex	Traumatic	Affected	Light	Reciprocal
5	M	65	185	92	0.8	16.5	Multiflex	Vascular	Affected	Reliant	Step to
6	M	71	165	63	1.3	15.0	Multiflex	Vascular	Affected	Reliant	Step to
Mean (SD)		56 (13)	176 (12)	78 (13)	3.5 (4.3)	17.0 (3.6)					
Non-fallers											
7	F	50	163	97	1.0	17.5	Dynamic	Clubfoot/Elective	Affected	Moderate	Reciprocal
8	M	82	169	88	3.3	18.0	Multiflex	Vascular	None	Moderate	Step to
9	F	70	147	49	22.0	14.0	Multiflex	Traumatic	Affected	Moderate	Step to
10	M	26	185	63	0.8	13.5	Variflex	Clubfoot/Elective	None	Light	Reciprocal
11	M	55	185	73	26.0	15.0	Multiflex	Traumatic	Affected	Light	Reciprocal
Mean (SD)		57 (21)	170 (16)	74 (19)	10.6 (12.3)	15.6 (2.0)					

'Light' handrail use was classified as using the handrail as a guide only (Reeves et al., 2008a). In the current study, light handrail meant that participants held the handrail with one hand only.

'Moderate' handrail use occurred when participants used both arms as a guide, but did not perform a large portion of the work with their arms.

'Reliant' handrail use occurred when participants performed considerable work with their arms and, when asked, would not have felt safe without the handrails.

Table 2: Mean (SD) temporal spatial and sagittal plane peak joint kinematics according to falls history and stair descent strategies

	RECIPROCAL STAIR DESCENT STRATEGY				STEP-TO STAIR DESCENT STRATEGY			
	Faller (n=4)		Non-faller (n=3)		Faller (n=2)		Non-faller (n=2)	
	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)
Speed (m/s)	0.72 (0.12)		0.50 (0.06)		0.24 (0.08)		0.34 (0.10)	
Stance phase (%)	57 (2)	60 (2)	58 (1)	63 (4)	59 (8)	81 (2)	44 (2)	76 (1)
Hip angle toe off (°)	40.7 (6.2)	37.3 (7.2)	49.8 (15.7)	54.2 (4.5)	44.7 (0.3)	46.3 (0.7)	44.8 (15.3)	42.3 (3.5)
Hip flexion swing (°)	49.5 (7.3)	47.7 (4.9)	51.0 (17.0)	58.3 (6.3)	51.2 (1.2)	52.7 (5.0)	53.4 (18.7)	48.3 (2.2)
Hip angle foot contact (°)	25.6 (3.9)	23.5 (5.1)	33.8 (13.6)	31.2 (1.6)	30.0 (5.5)	33.6 (3.9)	33.2 (12.8)	31.3 (4.7)
Hip extension stance (°)	-0.7 (2.9)	10.5 (5.8)	19.7 (13.6)	19.3 (6.1)	19.6 (1.7)	27.5 (1.7)	21.9 (14.1)	17.2 (6.8)
Hip ROM (°)	50.2 (9.1)	37.2 (7.5)	31.2 (8.3)	39.1 (6.6)	31.7 (3.0)	25.2 (3.3)	31.5 (4.6)	31.1 (4.7)
Knee angle toe off (°)	89.0 (3.9)	88.5 (6.4)	87.8 (5.9)	86.2 (2.4)	43.5 (7.5)	78.9 (1.6)	74.6 (42.8)	88.6 (5.3)
Knee flexion swing (°)	92.0 (5.0)	92.9 (5.6)	88.1 (5.6)	86.7 (1.5)	48.7 (5.7)	79.5 (0.8)	77.7 (44.5)	90.1 (4.0)
Knee angle foot contact (°)	6.4 (5.2)	8.4 (4.1)	12.2 (6.6)	4.6 (1.3)	16.6 (6.6)	17.9 (2.8)	21.9 (19.7)	25.6 (5.0)
Knee ROM (°)	86.9 (7.5)	87.1 (5.8)	78.8 (4.1)	83.9 (2.8)	39.2 (3.2)	68.3 (2.5)	57.7 (26.3)	72.3 (3.8)
Ankle angle toe off (°)	6.3 (3.7)	10.3 (5.0)	4.7 (2.9)	2.7 (10.9)	5.6 (3.0)	7.5 (11.5)	7.4 (7.7)	20.1 (0.0)
Ankle plantarflexion swing (°)	5.0 (3.5)	-23.6 (4.8)	3.8 (2.9)	-19.2 (8.7)	4.0 (1.1)	0.7 (6.5)	4.2 (5.2)	6.7 (1.2)
Ankle angle foot contact (°)	5.6 (4.2)	-20.5 (3.5)	3.8 (2.9)	-17.7 (8.5)	4.8 (0.7)	4.1 (1.7)	6.5 (4.6)	7.1 (0.6)
Ankle dorsiflexion stance (°)	15.8 (2.5)	29.2 (8.9)	15.7 (3.1)	25.6 (12.3)	10.8 (2.3)	30.8 (14.3)	15.9 (6.6)	40.4 (3.0)
Ankle ROM (°)	10.8 (1.1)	52.8 (6.0)	12.0 (3.0)	44.8 (20.4)	6.8 (1.2)	30.1 (7.9)	11.7 (1.4)	33.7 (4.2)
Pelvic tilt toe off (°)	15.3 (0.9)	14.7 (1.0)	20.8 (1.0)	24.2 (3.4)	22.9 (0.6)	19.5 (0.7)	18.6 (2.9)	19.2 (0.4)
Pelvic tilt swing (°)	15.7 (1.2)	20.0 (3.7)	23.4 (1.0)	26.2 (4.1)	22.9 (0.6)	21.6 (0.2)	20.4 (0.3)	20.2 (0.2)
Pelvic tilt foot contact (°)	14.6 (2.2)	18.2 (1.8)	21.8 (0.5)	23.1 (3.0)	19.1 (2.3)	20.9 (1.2)	19.6 (0.8)	18.0 (2.3)
Pelvic tilt stance (°)	16.6 (2.5)	18.2 (1.8)	22.6 (1.1)	24.1 (2.2)	23.3 (0.6)	14.6 (0.8)	20.0 (0.5)	13.3 (1.7)

Table 3: Mean (SD) frontal plane peak joint kinematics according to falls history and stair descent strategies

	RECIPROCAL STAIR DESCENT STRATEGY				STEP-TO STAIR DESCENT STRATEGY			
	Faller (n=4)		Non-faller (n=3)		Faller (n=2)		Non-faller (n=2)	
	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)	Affected (Lead)	Intact (Trail)
Hip angle toe off (°)	1.6 (3.6)	-1.9 (4.4)	2.7 (10.7)	2.5 (4.6)	2.2 (6.7)	2.3 (5.9)	4.3 (3.6)	1.7 (1.6)
Hip abduction swing (°)	-6.4 (3.7)	-13.7 (4.5)	-6.1 (2.3)	-10.7 (0.3)	-8.8 (4.3)	1.0 (4.8)	-8.3 (3.7)	-1.3 (0.7)
Hip angle foot contact (°)	-6.3 (3.5)	-13.7 (4.3)	-5.5 (3.0)	-10.7 (0.3)	-8.2 (4.8)	4.7 (2.5)	-8.3 (3.7)	3.3 (4.2)
Hip adduction stance (°)	0.0 (1.8)	3.6 (2.8)	5.0 (7.0)	6.4 (2.2)	4.6 (6.0)	5.7 (3.9)	0.1 (1.2)	8.8 (4.0)
Hip frontal ROM (°)	10.1 (1.7)	17.3 (5.0)	13.2 (9.1)	17.3 (1.8)	14.0 (0.7)	9.9 (4.7)	13.5 (0.9)	10.1 (3.3)
Pelvic obliquity toe off (°)	7.8 (3.3)	3.7 (2.0)	7.6 (4.5)	2.6 (1.3)	2.8 (0.8)	5.8 (3.6)	2.9 (5.1)	7.3 (0.6)
Pelvic obliquity foot contact (°)	-4.4 (2.0)	-5.6 (3.2)	-3.7 (1.6)	-7.4 (2.8)	-4.8 (1.7)	2.0 (1.2)	-8.5 (1.8)	4.5 (1.9)
Pelvic obliquity down stance (°)	-5.5 (1.5)	-7.4 (3.1)	-5.1 (3.1)	-8.5 (4.1)	-5.4 (2.4)	-4.3 (0.4)	-8.6 (1.8)	1.7 (0.7)
Pelvic obliquity up stance (°)	-0.6 (2.1)	4.2 (2.3)	-0.8 (4.0)	3.1 (2.9)	4.1 (0.4)	5.1 (2.0)	-1.6 (0.6)	10.0 (0.9)
Pelvic frontal ROM (°)	13.4 (4.8)	12.7 (5.0)	13.0 (7.5)	12.3 (5.9)	9.6 (2.2)	11.0 (3.8)	11.6 (3.3)	8.3 (1.6)

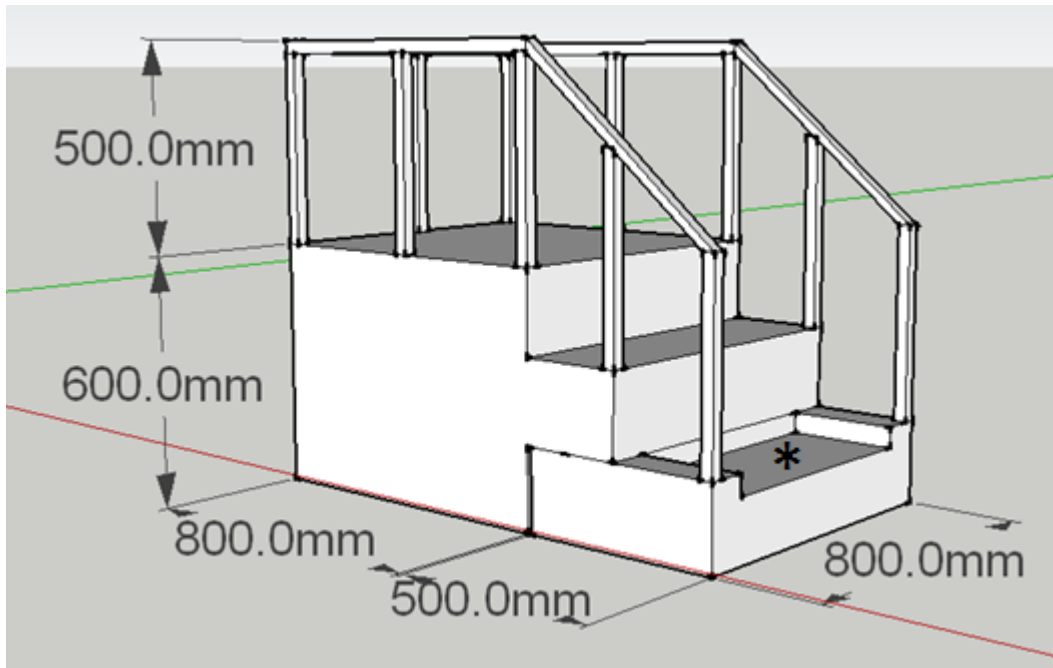


Figure 1. Illustration of the 3-step staircase used for stair descent and the step dimensions.

* Indicates location of the force plate on the bottom step, although kinetic data were not presented in this study.

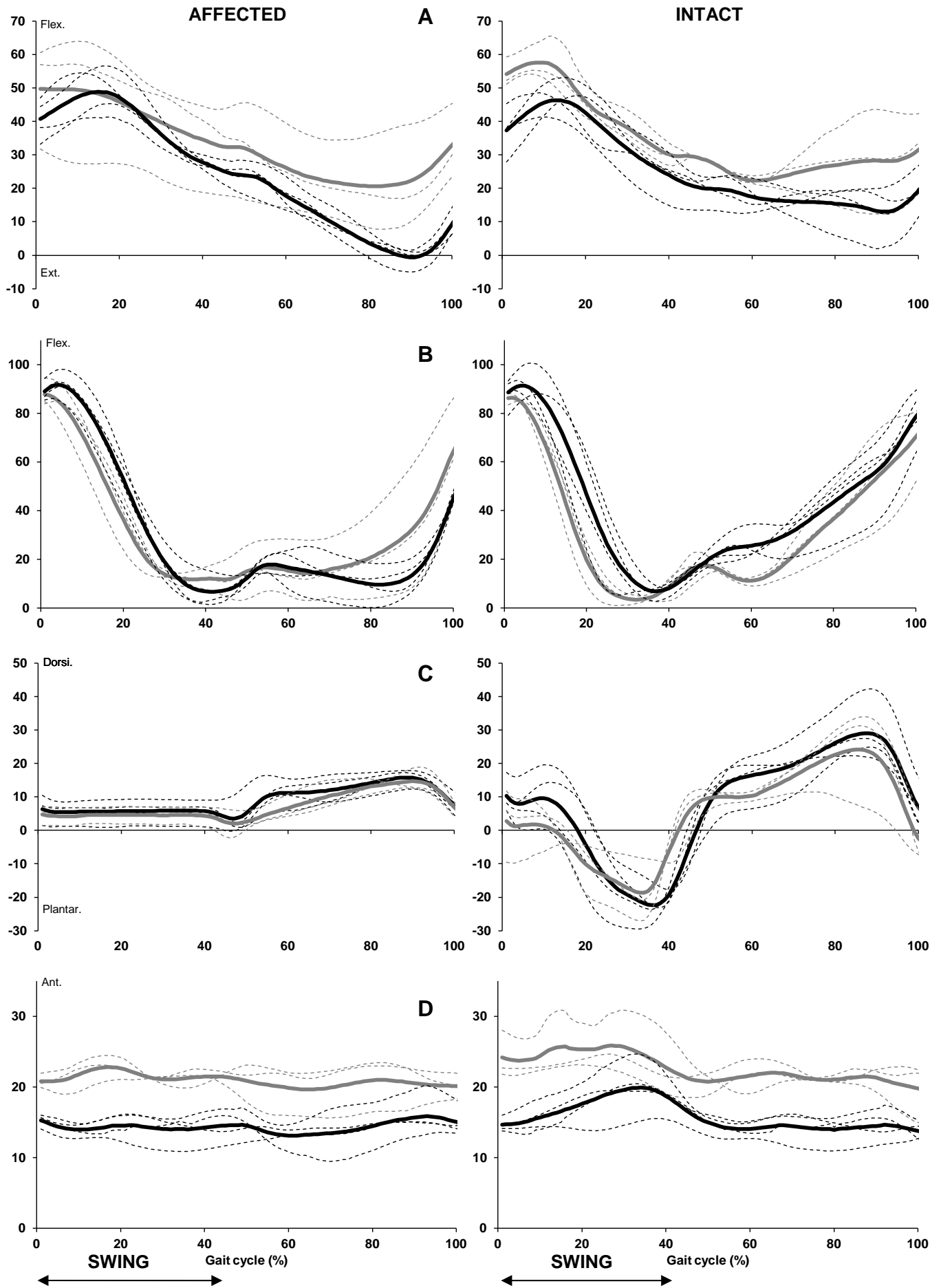


Figure 2. Average sagittal plane joint kinematics of the A) hip, b) knee, C) ankle and D) pelvis for the fallers (bold black line) and non-fallers (bold grey line) using a reciprocal stair descent strategy. Individual participant data are included for the fallers (dashed black line) and non-fallers (dashed grey line). Hip and knee flexion, ankle dorsiflexion and anterior pelvic tilt are positive. Hip and knee extension, ankle plantarflexion and posterior pelvic tilt are negative. The gait cycle is initiated and terminated with toe off.

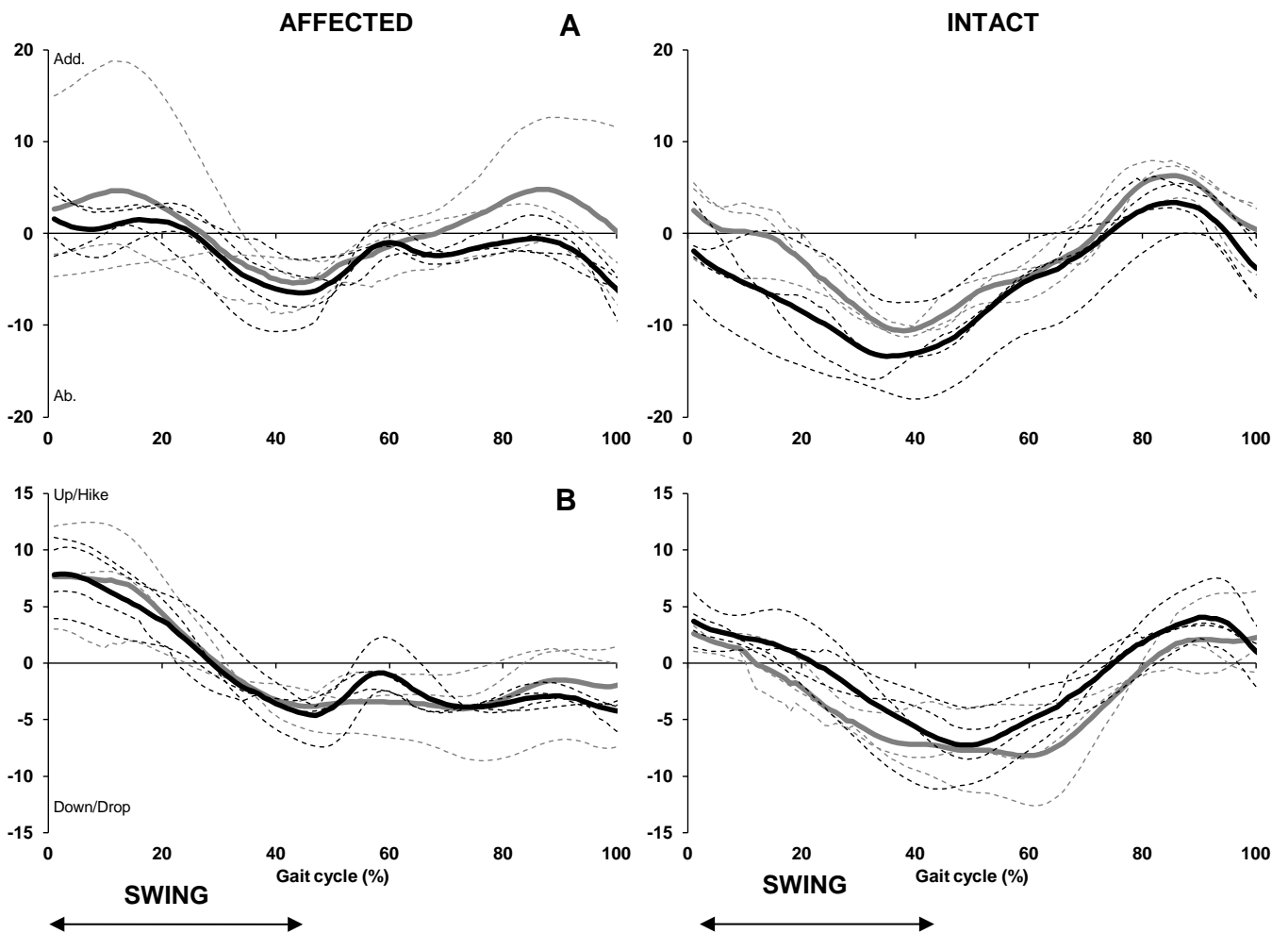


Figure 3: Average frontal plane joint kinematics of the A) hip, and B) pelvis for the fallers (bold black line) and non-fallers (bold grey line) using a reciprocal stair descent strategy. Individual participant data are included for the fallers (dashed black line) and non-fallers (dashed grey line). Hip adduction and pelvic obliquity up (pelvic hike) are positive. Hip abduction and pelvic obliquity down (pelvic drop) are negative. The gait cycle is initiated and terminated with toe off.