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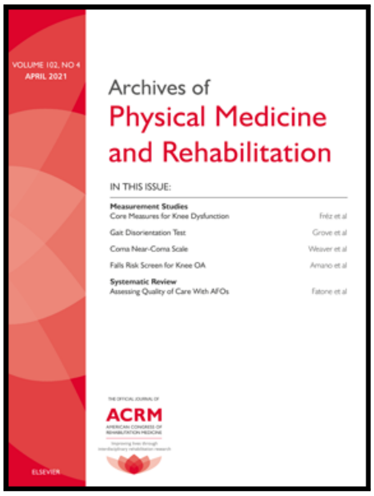


# Factors associated with walking adaptability and its association with falling in polio survivors

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Highlights

- Walking adaptability was assessed with target-stepping and obstacle-avoidance tests
- Target stepping was determined by leg-muscle strength and balance confidence
- Obstacle avoidance was solely determined by leg-muscle strength
- Target stepping was related to falling, while obstacle avoidance not.
- Foot-placement limitations may increase the fall risk among polio survivors

**Factors associated with walking adaptability and its association with falling in polio survivors**

*Walking adaptability in polio survivors*

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<u>Reprints added to submission:</u> Validity and reproducibility of C-Mill walking-adaptability assessment in polio survivors, submitted to Gait & Posture in June 2021, using the same baseline data to evaluate the validity and reproducibility of walking-adaptability assessment.

**Objective** To explore factors associated with walking adaptability and associations between walking adaptability and falling in polio survivors.

**Design** Cross-sectional study.

**Setting** Outpatient expert polio clinic.

**Participants** Polio survivors (n=46) who fell in the previous year and/or reported fear of falling.

**Interventions** Not applicable.

**Main outcome measures** Walking adaptability was assessed on an interactive treadmill and operationalized as variable target-stepping and reactive obstacle-avoidance performance. Further, we collected walking speed and assessed leg muscle strength, balance performance (Berg Balance Scale and Timed-Up-and-Go Test), balance confidence (Activities-specific Balance Confidence scale), ambulation level, orthosis use, fear of falling and number of falls in the previous year.

**Results** With walking speed included as covariate, muscle weakness of the most affected leg and balance confidence explained 54% of the variance in variable target-stepping performance. For reactive obstacle-avoidance performance, muscle weakness of the most affected leg and knee extensor strength of the least affected leg explained 32% of the variance. Only target-stepping performance was significantly related to the number of falls reported in the previous year ($R^2$=0.277, p<0.001), and mediated the relation between leg muscle weakness and balance confidence with falling.

**Conclusion** Our exploratory study suggests that leg muscle weakness and reduced balance confidence limit walking adaptability in polio survivors. As poorer target-stepping rather than obstacle-avoidance performance was associated with falling, our results indicate that a limited ability to ensure safe foot placement may be a fall risk factor in this group. These findings should be confirmed in a larger sample.

**Key words** Postpoliomyelitis Syndrome, Accidental Falls, Locomotion, Mobility Limitations

**List of abbreviations**

| | |
|---|---|
| ABC | Activities-specific Balance Confidence |
| BBS | Berg Balance Scale |
| CWS | Comfortable walking speed |
| CoP | Centre of Pressure |
| FES | Falls Efficacy Scale |
| FoF | Fear of falling |
| MRC | Medical Research Council |
| TUG | Timed-Up-and-Go Test |
| VE | Variable stepping Error |

Aging survivors of polio have a fall rate 2-3 times higher [1-4] than comparable community-dwelling healthy individuals [5], and many falls result in (severe) injuries that impact daily activities, independent living and quality of life [2, 6, 7]. Falls mostly occur during walking [2], an activity of daily life that requires continuous adaptation to task goals and environmental circumstances (walking adaptability). Walking adaptability can be conceptualized into nine domains [8], including obstacle negotiation, walking on uneven surfaces and manoeuvring during walking [8, 9]. Using the C-Mill interactive treadmill (Figure 1), we previously found that polio survivors show poorer walking adaptability as expressed in reduced obstacle-avoidance performance (mimicking obstacle negotiation) and less precise target stepping (mimicking walking on uneven surfaces) when compared to healthy individuals [10].

Together with the ability to generate step movements and maintain balance, walking adaptability is an essential aspect of safe and independent walking [8, 9]. Early identification of limitations in walking adaptability is therefore important, but we first need a better understanding of factors associated with walking adaptability in polio survivors. In neurological disorders such as Parkinson's disease or stroke, balance problems, weakness of the hip abductor and quadriceps muscles, previous falls and impaired executive function are associated with reduced walking adaptability [11, 12]. However, factors related to walking adaptability in the abovementioned groups may not be directly transferable to a neuromuscular disorder such as polio.

Most falls in polio survivors occur after tripping, slipping or missteps [2, 6], suggesting an association between reduced walking adaptability and falling. Although not confirmed in polio survivors, a similar association has been found in community-dwelling elderly [13] and in people with

Parkinson's disease [14]. Previously identified factors associated with risk of falls in polio survivors include intrinsic problems such as leg muscle weakness [15] (specifically of the most affected leg [2, 4, 16]), fear of falling [2, 16, 17], self-reported balance problems [2] and reduced walking speed [16]. Nevertheless, extrinsic factors such as environmental circumstances might also be involved [18] but have yet to be studied.

Our goals in the present study were therefore to 1) explore factors associated with walking adaptability (target-stepping performance and obstacle-avoidance performance) in polio survivors, and 2) explore associations between walking adaptability and falling.

**Methods**

*Study design*

Data for this cross-sectional study originate from a 2-year prospective cohort study on walking adaptability in polio survivors, with measurements taken at baseline, two weeks, 1 year and two years. Here we used data collected at the two-week point to account for learning effects [19]. The study protocol was previously approved by the medical ethics committee of the Academic Medical Center (AMC, Amsterdam, the Netherlands). Study reporting was in accordance with the 'Strengthening Reporting of Observational Studies in Epidemiology' recommendations [20].

*Participants*

Polio survivors (*n*=48) were recruited from the outpatient clinic of the department of Rehabilitation Medicine of the Amsterdam UMC, location AMC, from December 2016 to August 2018. Inclusion criteria were: aged between 18 and 80 years, able to walk indoors without assistive devices (e.g. crutch, cane or walker), and > 1 fall reported in the previous year and/or fear of falling. A diagnosis of any other medical condition that increases fall risk was an exclusion criterion. Participants provided written informed consent prior to study enrolment.

*Procedures*

Data used in this study included walking-adaptability outcomes, leg muscle strength, balance performance, balance confidence, walking ability, fear of falling and fall frequency.

*Walking adaptability*

Participants performed walking-adaptability tests on the C-Mill interactive treadmill [a] as described previously [10]. After a familiarization protocol (4-5 minutes) and determination of comfortable treadmill walking speed (CWS, in m/s), participants first performed three target-stepping tasks, followed by two obstacle-avoidance tasks. For both tasks, the most challenging conditions were used in the current study because of superior reproducibility compared to the easier conditions [19]. All tests were performed at fixed CWS and a safety harness without weight bearing was used to prevent falling. Participants used their customary orthosis during testing.

*Variable target stepping* was assessed while following a sequence of rectangular step targets, projected with 30% inter-target variation relative to the participants' own gait pattern, for two minutes. Participants were asked to centre their feet in the step targets, which were 3 cm larger than their right foot. Target-stepping performance was calculated over goal-directed steps, i.e. with the midstance CoP located within the target boundaries, defined as the Variable stepping Error (VE, in mm). The VE was calculated as the standard deviation over the distances from the middle of the step target to the midstance CoP using MATLAB 2019a[b]. A smaller VE represents better target-stepping performance. For *reactive obstacle avoidance*, 12 obstacles (30 cm long and as wide as the treadmill belt) were projected onto the treadmill belt at the anticipated foot contact location. Successful avoidance was scored when both feet were positioned outside the obstacle boundaries without handrail use. Obstacle-avoidance success rate (%) was calculated when at least 10 obstacles were projected onto the treadmill, and higher percentages represent better performance.

*Leg muscle strength*

Muscle strength was assessed manually according to the Medical Research Council (MRC) scale (range 0-5) [21] for eight muscle groups per leg. We calculated left and right MRC sum-scores (range 0-40, note: in case of an ankle arthrodesis, the dorsal and plantar MRC of that side were set at zero [22]) and we defined a most and least affected leg (i.e. lowest and highest MRC sum-score, respectively). We calculated MRC asymmetry-scores by taking the absolute value of the difference in left and right MRC sum-scores [22].

For the left and right knee extensors, we measured isometric strength on a fixed dynamometer[c]. Participants were seated with the back of the chair positioned in 85° and with the knee in 60° flexion. Maximal strength was defined as the peak torque (in Nm) of three maximal voluntary isometric contractions of 5 seconds, interspersed with periods of 30 seconds rest.

*Balance performance and balance confidence*

Balance performance was assessed with the Berg Balance Scale (BBS) and the Timed-Up-and-Go test (TUG). The BBS-score (range 0 to 56, higher scores indicate better balance performance) is summed from 14 activity items (range 0 to 4), indicating whether a participant is able to perform the activity (independently) [23]. The TUG-score represents the time (in seconds) needed to rise from a chair, walk three meters, turn

Abbreviations: 95% CI: 95% Confidence Interval, ABC: Activities Specific Balance Confidence, MRC: Medical Research Council, BBS: Berg Balance Scale, CWS: comfortable walking speed, TUG: Timed-Up-and-Go Test.
*For the multiple regression model: $R^2$=0.316

**Table 4** Results of the mediation analysis

| Fall-risk factor (X) | Indirect effect | | | | | | Direct effect | | | Total effect | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Path a | | | Path b | | | Path c | | | | | |
| | *A (SE)* | 95% CI of *A* | p-value | *B (SE)* | 95% CI of *B* | p-value | *C (SE)* | 95% CI of *C* | p-value | Coefficient | 95% CI of Coefficient | p-value |
| ABC-score | -0.151 (0.057) | [-0.266, -0.035] | 0.012 | 0.110 (0.032) | [0.044, 0.175] | 0.002 | -0.024 (0.013) | [-0.050, 0.002] | 0.068 | -0.040 (0.013) | [-0.067, -0.014] | 0.004 |
| MRC-sum score (most-affected leg) | -0.406 (0.115) | [-0.639, -0.174] | 0.001 | 0.113 (0.034) | [0.044, 0.183] | 0.002 | -0.30 (0.029) | [-0.089, 0.028] | 0.301 | -0.076 (0.028) | [-0.133, -0.019] | 0.010 |

Mediation effects (A/B/C/Coefficient) of fall-risk factor (X) on the number of falls reported in the previous year (Y), with target-stepping performance as mediator (M) and CWS as covariate. For the mediation model, see Figure 2.
Abbreviations: 95% CI = 95% Confidence Interval, ABC = Activities-specific Balance Confidence scale; MRC = Medical Research Council; SE = standard error