ORIGINAL REPORT

SIX MINUTES WALKING IN POLIO SURVIVORS: EFFECTS ON FATIGUE AND WALKING ADAPTABILITY

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Objective: **To investigate whether 6-min walking is fatiguing for polio survivors, and how fatigue influences their normal and adaptive walking.**
Design: **Cross-sectional study.**
Patients: **Polio survivors ($n=23$) with ≥1 fall and/or fear of falling reported in the previous year and healthy individuals ($n=11$).**
Methods: **Participants performed 1 normal-walk test and 2 walking-adaptability tests (target stepping and narrow-beam walking) on an instrumented treadmill at fixed self-selected speed, each test lasting 6 min. Leg-muscle fatigue (leg-muscle activation, measured with surface electromyography), cardiorespiratory fatigue (heart rate, rate of perceived exertion), gait and walking-adaptability performance were assessed. The study compared: *(i)* the first and last minute per test, *(ii)* normal and adaptive walking, and *(iii)* groups.**
Results: **Leg-muscle activation did not change during normal walking ($p>0.546$), but declined over time during adaptive walking, especially in polio survivors ($p<0.030$). Cardiorespiratory fatigue increased during all tests ($p<0.001$), especially in polio survivors ($p<0.01$), and was higher during adaptive than normal walking ($p<0.007$). Target-stepping performance declined in both groups ($p=0.007$), while narrow-beam walking improved in healthy individuals ($p<0.001$) and declined in polio survivors ($p<0.001$).**
Conclusion: **Cardiorespiratory fatigue might further degrade walking adaptability, especially among polio survivors during narrow-beam walking. This might increase the risk of falls among polio survivors.**

Key words: postpoliomyelitis syndrome; accidental falls; muscle fatigue; fatigue; gait; walking.

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LAY ABSTRACT

This study investigated whether prolonged walking is fatiguing for polio survivors and how this affects their ability to adapt walking to environmental circumstances (i.e. walking adaptability), which is an important skill for safe daily-life walking. A total of 23 polio survivors and 11 healthy individuals performed 1 normal-walk test and 2 walking-adaptability tests. To assess fatigue, leg-muscle activation, heart rate and rate of perceived exertion were measured. In addition, gait and walking-adaptability outcomes were assessed. The first and last minute per test, normal and adaptive walking, and groups were compared. Based on higher leg-muscle activation, heart rate and rate of perceived exertion, the study concluded that 6-min walking was more fatiguing for polio survivors than for healthy individuals and that adaptive walking was more fatiguing than normal walking, especially in polio survivors. Walking-induced fatigue further limits walking adaptability among polio survivors, which could increase their fall risk.

Muscle weakness of the lower extremities is common among people who have had a poliomyelitis (polio) infection (1), and causes walking problems (2) and an increased risk of falls (3). In this population, the severity of lower-extremity muscle weakness is strongly related to an increased energy cost of walking (4), which makes walking fatiguing (5), and frequently leads to fatigue symptoms (1, 6, 7). Polio-related fatigue symptoms negatively affect physical mobility and daily-life functioning (2).

Polio survivors typically experience fatigue as "an increasing loss of strength during exercise" or "a heavy sensation in the muscles" (6), suggesting that muscle fatigue plays a prominent role in causing fatigue (7). Whereas some studies have confirmed increased muscle fatigue in polio survivors compared with healthy individuals (8, 9), others have not (10–12). Importantly, in these studies, fatigue was induced by isometric contractions, which may not be representative of muscle fatigue experienced during daily-life activities, such as walking. To date, only 2 studies have evaluated rate of perceived exertion (RPE) and heart rate (HR) during walking in polio survivors (5, 13), which might reflect cardiorespiratory fatigue, but not muscle fatigue.

In polio survivors, leg-muscle fatigue during walking has not been studied to date, whereas in other clinical populations, such as people with multiple sclerosis (14) and cerebral palsy (15), leg-muscle fatigue occurred during walking and affected gait performance, which might increase their fall risk. The same may hold for polio survivors, because both fatigue (6) and fall rate (3, 16) have been reported to increase during the day. Walking-related falls in polio survivors mostly occur after tripping, slipping or misplaced steps (3, 16), possibly because polio survivors are less able to avoid such perturbations, due to reduced walking adaptability. We recently confirmed reduced walking adaptability in polio survivors (17). This raises the question as to whether walking-induced fatigue increases polio survivors' walking-related fall risk by further degrading their already limited walking-adaptability performance.

This study addressed this question by examining the effects of 6-min normal and adaptive walking on: (i) leg-muscle fatigue and cardiorespiratory fatigue; and (ii) gait and walking-adaptability outcomes in polio survivors and healthy individuals. Adaptive walking was operationalized as the ability to follow a sequence of irregularly positioned stepping targets and as the ability to follow a narrow-beam projection. Leg-muscle fatigue was assessed with surface electromyography (EMG) and parameterized by the root mean square (RMS) amplitude (18). When muscles fatigue during submaximal activity, more motor units are recruited and firing rate is increased to maintain the same force output, which is reflected as an increase in RMS amplitude (19). It was hypothesized that an increase in muscle and cardiorespiratory fatigue would occur from the first to the sixth minute, and more so for adaptive than for normal walking and for polio survivors than for healthy individuals. It was further hypothesized that this would be accompanied by a decrease in walking adaptability from the first to the sixth minute, again more so for polio survivors than for healthy individuals.

METHODS

For this cross-sectional study, participants of an observational 2-year follow-up study on walking adaptability were approached to participate (see (17) for a description of the tests involved in that study). The study protocol was 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 (STROBE) recommendations (20).

Participants

This study aimed to include 24 polio survivors and 12 healthy individuals to enable counterbalancing the order of the tests over participants (see below). Participants were aged between 18 and 80 years. Polio survivors were able to walk indoors without assistive devices (e.g. crutch, cane or walker) for at least 6 min, encountered at least 1 fall in the previous year and/or experienced fear of falling. Neither polio survivors nor healthy individuals had medical conditions associated with an increased fall risk (other than polio for the polio survivors). Participants signed informed consent before study enrollment.

Procedures and measurements

For polio survivors, the number of falls in the previous year was obtained via a questionnaire. Leg-muscle strength scores were used from the baseline measurements of the 2-year longitudinal study (17), as assessed with the Medical Research Council (MRC) scale score (range 0–5, lower scores indicating lower strength) (21) for 8 lower-extremity muscle groups. MRC sum-scores were calculated per leg from the individual MRC scores and used to define most and least-affected legs (i.e. lowest and highest MRC score, respectively). All participants performed a normal-walk test and 2 walking-adaptability tests, each lasting 6 min, with simultaneous assessment of leg-muscle fatigue (EMG) and cardiorespiratory fatigue (HR and RPE). Prior to the first walk test, baseline RPE after 8 min rest while sitting in a chair was assessed.

Fatigue assessment. To assess leg-muscle fatigue, sEMG-signals were recorded at 2,000 Hertz (Hz) (Cometa Wave Plus system, Barregio, Milan, Italy). Wireless electrodes were placed on both legs, on clean and shaved skin over the m. vastus lateralis (VL), m. soleus (SO) and m. tibialis anterior (TA) according to the guidelines of the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) (22). If the electrode location was immediately under the patient's orthosis or orthopaedic shoe, electrode placement was shifted slightly to prevent irritation. To assess cardiorespiratory fatigue, HR was measured continuously during the walk tests (Polar Electro, Kempele, Finland) and RPE was assessed after each minute of the walk tests with the Borg scale (range 6–20) (23).

Gait and walking-adaptability assessment. Walk tests were performed on an instrumented treadmill (C-Mill, Motek, Amsterdam, The Netherlands) with visual-context projections on the belt's surface (i.e. stepping targets: Fig. 1a, narrow beam: Fig. 1b). The C-Mill is

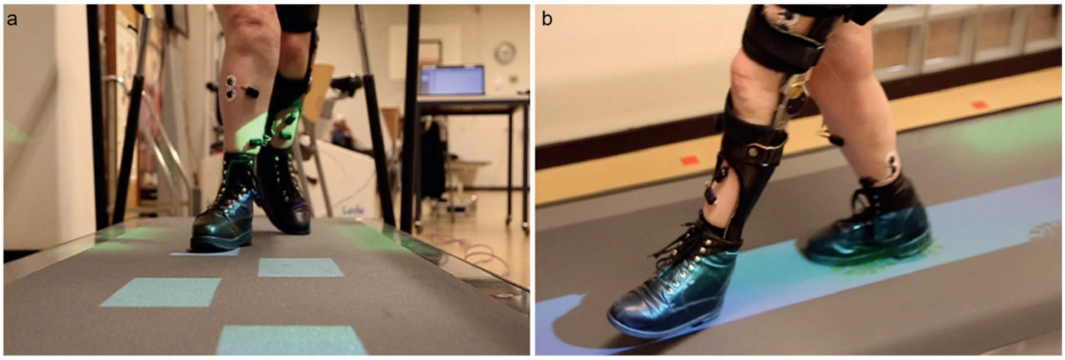

Fig. 1. Walking-adaptability tests on the C-Mill. (a) Target-stepping test. (b) Narrow-beam walking test.

equipped with 1 large force platform to collect the centre of pressure (CoP), which is used to detect gait-cycle events and foot-placement locations (CueFors, version 2.3.4 and 2.4.0) (24). In between walk tests, participants rested while seated on a chair for as long as they desired, but at least until they reached their baseline RPE.

Walk tests were performed in counterbalanced order (i.e. the possible 6 orders of the 3 walking tests were sequentially distributed over participants before inclusion, implying a sample size in multiples of 6 for full counterbalancing), at fixed, self-selected comfortable treadmill walking speed (in m/s), determined prior to the first test (see (25)). During the normal-walk test, the mean and variability (calculated as the standard deviation (SD)) of step time (s) and step width (cm) were recorded. During target stepping, participants were instructed to place their feet in rectangular step targets, 3 cm longer than their right foot, as accurately as possible. Step length and step width, as imposed by the projected stepping targets, varied with 20% random variation relative to the mean gait pattern of the participant, as recorded prior to target presentation. During narrow-beam walking, participants were instructed to place their feet as accurately as possible in the narrow-beam projection while walking. The width of the beam changed every minute in a fixed order (i.e. 15, 25, 20, 10, 20, 15 cm) to challenge balance and avoid boredom. The equal width in the first and sixth minute of the test enabled a fair comparison of the effects of time on narrow-beam walking.

Data analysis

To avoid transient effects, muscle-fatigue and normal-gait outcomes were derived from the final 40 s of each min, while walking-adaptability outcomes were calculated after removing the first 10 steps.

Muscle and cardiorespiratory-fatigue analysis. EMG signals were processed offline in Matlab (The Mathworks, version R2021a, Natick, MA, USA). A 20-Hz high-pass filter was applied to remove movement artefacts. The RMS was calculated over a sliding window of 133 samples without overlap, to obtain a smooth linear envelope of the EMG signal. EMG recordings were normalized by the mean RMS amplitude over all 3 walk tests and divided into gait cycles using foot-contact indices of CueFors. The mean RMS per muscle over all included gait cycles in the first and sixth minute of the walk tests was then calculated. RMS values were averaged over both legs, since values did not differ significantly between most and least-affected legs. For cardiorespiratory fatigue, the mean HR was calculated in the first and sixth minute of the tests and, for the RPE, the Borg score obtained after the first and sixth minute was used.

Gait and walking-adaptability analysis. For normal walking, spatiotemporal gait parameters were calculated as described previously (26), using foot-contact indices (24). For target stepping, only steps for which the CoP-position at midstance fell within the target boundaries were included to assure goal-directed stepping (17). Over these steps, the variable stepping error (VE, in mm) was calculated as the standard deviation over the distances from the centre location of the stepping target to the CoP-location at midstance. A lower VE indicates more precise target stepping (27). Step-time and target stepping were calculated per leg in polio survivors (i.e. most-affected vs least-affected leg) and were averaged over the left and right leg in healthy individuals. For narrow-beam walking, the mean step width (in cm) was calculated. A smaller step width indicates better performance.

Statistical analysis

After checking for normality, repeated-measures analyses of variance (ANOVAs) were conducted in IBM SPSS Statistics 26. To evaluate the effects of 6-min walking on fatigue in both polio survivors and healthy individuals, a Time × Group × Task × Muscle repeated-measures ANOVA on RMS-amplitudes and a Time × Group × Task repeated-measures ANOVA on

HR and RPE were performed. In case of significant interactions with the factor Time, Group or Task, we continued with lower-level comparisons in order to evaluate differences between the first and sixth minute of the tests (i.e. factor Time), between polio survivors and healthy individuals (i.e. factor Group) and between normal walking and adaptive walking (i.e. factor Task).

To determine the effect of 6-min walking on normal gait and walking adaptability, a Time × Group repeated-measures ANOVA was performed separately for each Task given the different dependent variables (i.e. gait parameters, target-stepping performance, and narrow-beam-walking performance). Significant interactions were further analysed by comparing the first and the sixth minute of the tests separately for both groups. The effect of Group and its interaction with Time were determined to examine whether effects were more pronounced in polio survivors than in healthy individuals. Since polio survivors walked significantly slower (0.61 ± 0.17 m/s) than healthy individuals (0.98 ± 0.21 m/s, $p < 0.001$), walking speed was added as a covariate for normal walking and target stepping between-subjects effects and interactions (27). For step time and VE (i.e. outcomes calculated per leg), Group had 3 levels: polio survivors' most-affected leg, polio survivors' least-affected leg and healthy individuals (averaged over both legs).

Independent *t*-tests (between-subjects comparisons) and paired-samples *t*-tests (within-subject comparisons) were used for post-hoc analysis. For all analyses, $p < 0.05$ was considered significant with no adjustment for multiple comparisons.

RESULTS

Participants' characteristics

A total of 23 polio survivors (of whom 20 were diagnosed with post-polio syndrome, as derived from their medical status) and 11 healthy individuals were included in the study (Table I).

Normal walking and target-stepping performance were analysed for 22 instead of 23 polio survivors, since 1 participant with polio could only complete narrow-beam walking, but not the other tests, because of exhaustion. RMS-amplitudes of 19 polio survivors and 10 healthy individuals were analysed, HR for 21 polio survivors and 8 healthy individuals and RPE for 22 polio survivors and 11 healthy individuals, since some data were missing due to missing synchronization with the C-Mill, and for 2 polio survivors it was not possible to place the EMG-electrodes on the correct muscle position.

Table I. Socio-demographics and clinical characteristics of all participants

	Polio survivors ($n=23$)	Healthy individuals ($n=11$)	*p*-value
Socio-demographics			
Sex (M/F), *n*	4/19	8/3	
Age, years, mean (SD)	66.2 (6.3)	67.6 (6.4)	0.558
Mass, kg, mean (SD)	74.6 (10.6)	81.5 (15)	0.129
Diagnosed with PPS (yes/no), *n*	20/3		
Clinical characteristics			
MRC sum score (most-/least-affected leg), median [IQR]	26 [15]/39 [3]		
BBS score, mean (SD)	52.2 (5.0)		
TUG score (time, s), mean (SD)	12.8 (3.5)		
Fall frequency, *n* (%)			
Weekly	2 (9)		
Monthly	4 (17)		
<Once a month	7 (30)		
Never	10 (44)		
Orthoses, *n* (%)			
None	4 (17)		
AFO	10 (44)		
KAFO	9 (39)		

MRC: Medical Research Council; AFO: ankle-foot orthosis, KAFO: knee-ankle-foot orthosis; SD: standard deviation; IQR: interquartile range; M: male; F: female; PPS: postpoliomyelitis syndrome; BBS: Berg Balance Scale; TUG: Timed Up and Go test.

Leg-muscle fatigue

Neither the main effect of Muscle or any interaction effects with Muscle were significant. The Time × Group × Task interaction was significant ($p=0.041$). Post-hoc analyses for the factor Time indicated no change in RMS-amplitudes from the first to the sixth minute during normal walking in both healthy individuals ($p=0.651$) and polio survivors ($p=0.546$). During target stepping, RMS-amplitudes did again not change from the first to the sixth minute in healthy individuals ($p=0.461$), while they declined in polio survivors ($p=0.030$). During narrow-beam walking, RMS-amplitudes declined from the first to the sixth minute in both healthy individuals ($p<0.001$) and polio survivors ($p=0.005$, Fig. 2).

Post-hoc analyses for the factor Group revealed that RMS-amplitudes did not differ between polio survivors and healthy individuals in the first minute during normal walking ($p=0.077$) and during target stepping ($p=0.628$), while during narrow-beam walking, RMS-amplitudes were lower in polio survivors than in healthy individuals ($p=0.002$). In the sixth minute of all tests, RMS-amplitudes did not differ between groups ($p>0.120$).

Post-hoc analyses for the factor Task revealed that RMS-amplitudes were significantly lower during normal walking than during both adaptive-walking tasks in the first minute of the tests ($p<0.001$ for both groups), while RMS-amplitudes did not differ between target stepping and narrow-beam walking tasks ($p>0.070$). In healthy individuals, this remained unchanged for the sixth minute (i.e. lower RMS-amplitudes during normal walking than during adaptive-walking tasks: $p<0.007$; no difference

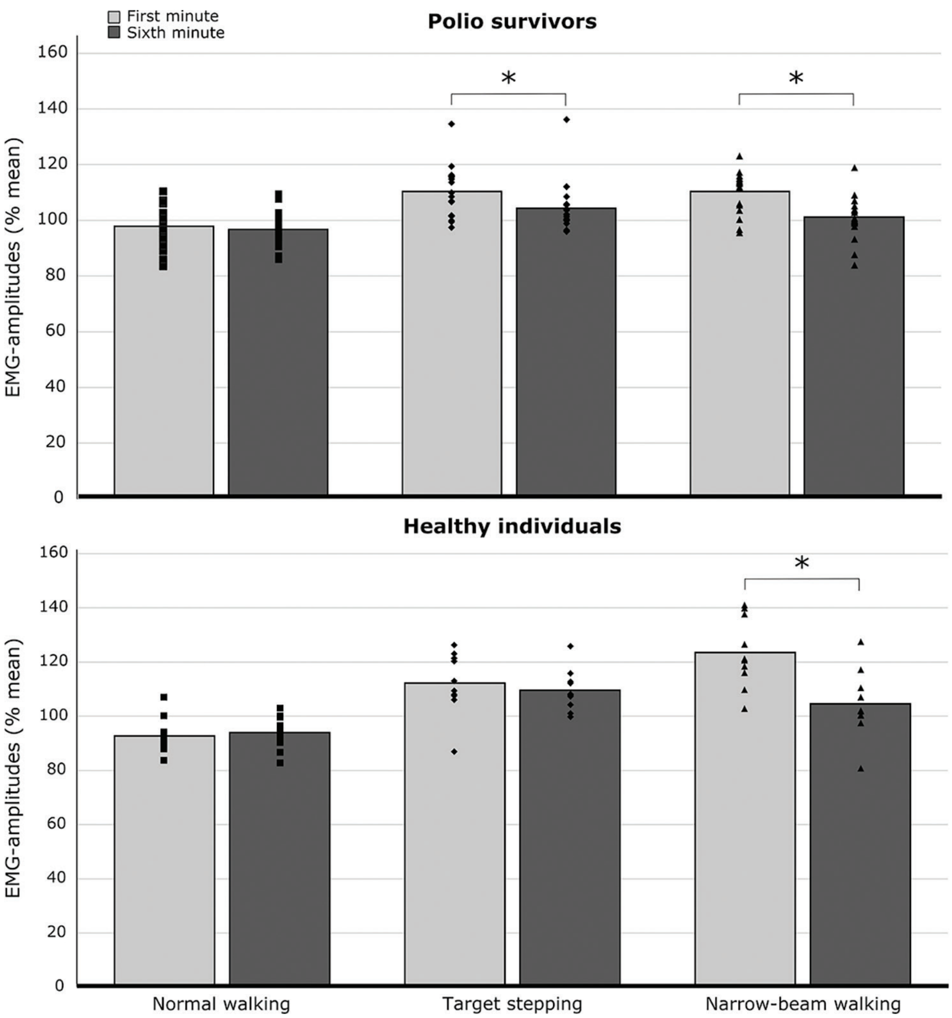

Fig. 2. Leg-muscle fatigue. Mean root mean square (RMS)-amplitudes over the 3 muscles (m. vastus lateralis, m. soleus and m. tibialis anterior) are shown for polio survivors (*upper panel*: $n=19$) and healthy individuals (*lower panel:* $n=10$), as percentage of the mean RMS-amplitude over all 3 walk tests. *Squares* (normal walking), *diamonds* (target stepping) and *triangles* (narrow-beam walking) represent individual data-points. *$p<0.05$.

in RMS amplitudes between target-stepping and narrow-beam-walking tasks: $p=0.698$). For polio survivors, RMS amplitudes in the sixth minute did not differ between normal-walking and narrow-beam-walking tasks ($p=0.269$) and between narrow-beam-walking and target-stepping tasks ($p=0.756$), while RMS amplitudes were significantly higher for target-stepping than for normal-walking tasks ($p=0.023$).

Cardiorespiratory fatigue

The increase in both HR and RPE from the first minute to the sixth minute was more pronounced for polio survivors than for healthy individuals (i.e. significant Time × Group-interactions) and HR and RPE were overall significantly higher for polio survivors than for healthy individuals (Fig. 3). A significant main effect of Task was found for HR ($p<0.001$) and RPE ($p=0.007$). HR was higher during both adaptive-walking tasks than during the normal-walking task ($p<0.004$). RPE was higher during the narrow-beam-walking task than during target-stepping ($p=0.033$) and during normal-walking tasks ($p=0.004$), while the RPE during normal-walking and target-stepping tasks did not differ ($p=0.184$). Besides the Time × Group interactions, other interactions with Time, Group and Task were not significant ($p>0.052$).

Gait and walking-adaptability performance

For normal walking, this study only observed a difference in step time between least-affected and most-affected legs in persons with polio ($p=0.001$), without any other significant Group, Time and Group × Time effects for spatiotemporal gait parameters (Table II). For target stepping, VE increased significantly over Time, indicating less precise target stepping ($p=0.007$, Fig. 4), without significant Group and Time × Group-effects ($p>0.727$). For narrow-beam walking, a significant Time × Group interaction indicated increased step width in the sixth compared with the first minute in polio survivors ($p<0.001$), while step width significantly decreased in healthy individuals ($p<0.001$, Fig. 4 and Table II).

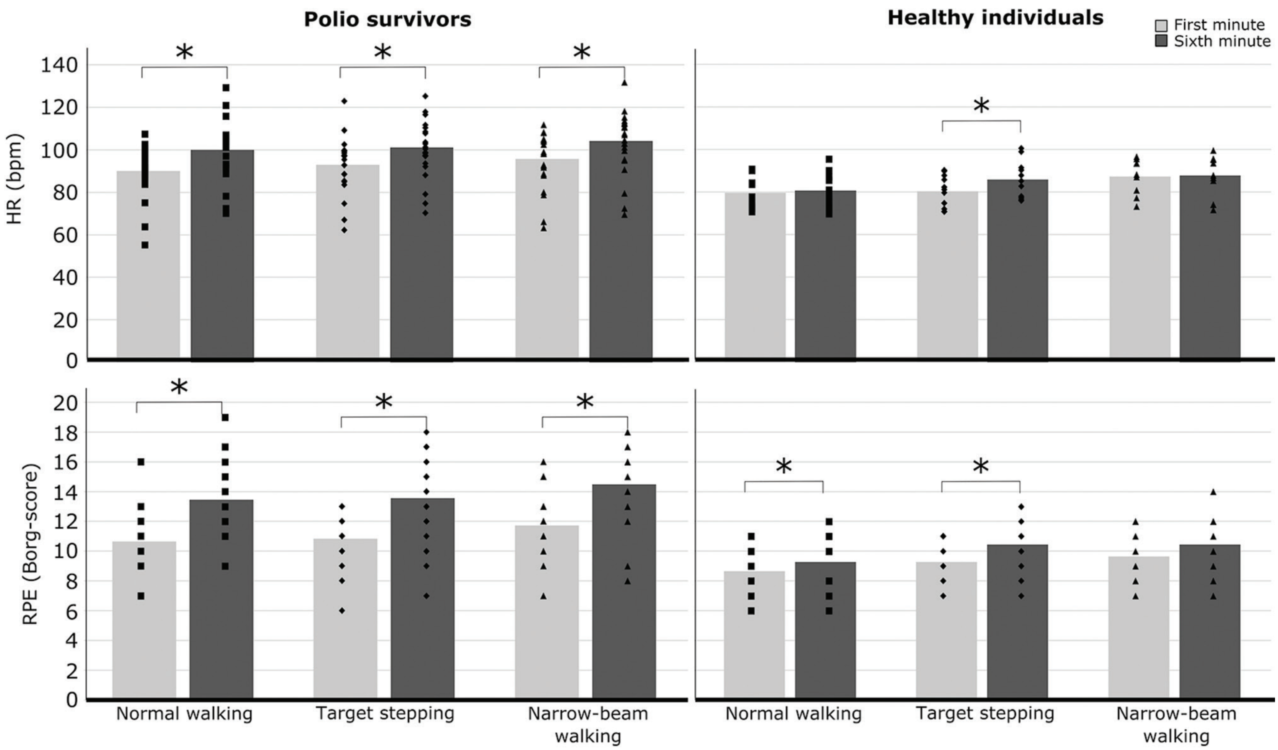

Fig. 3. Cardiorespiratory fatigue. Heart rate (HR) in beats per min (bpm) (*upper panels*) and rate of perceived exertion (RPE as measured by the Borg-score) (*lower panels*) are shown for polio survivors (*left-hand panels*) and healthy individuals (*right-hand panels*) for the first and sixth minute of the tests. *Squares* (normal walking), *diamonds* (target stepping) and *triangles* (narrow-beam walking) represent individual data-points. *$p < 0.05$.

DISCUSSION

The aim of this study was to evaluate whether leg-muscle fatigue and cardiorespiratory fatigue occurred during 6-min normal and adaptive walking, and how this influenced normal gait and walking adaptability performance in polio survivors and healthy individuals. The results suggest that 6-min walking was more demanding for polio survivors than for healthy individuals, as indicated by a more pronounced increase in cardiorespiratory fatigue. The study further found that adaptive walking was more demanding than normal walking, as indicated by higher cardiorespiratory fatigue and higher muscle activation. In contrast to our expectations, muscle activation of polio survivors decreased during adaptive walking, accompanied by a decline in walking-adaptability performance. The results suggest that especially adaptive walking induced cardiorespiratory fatigue in polio survivors, which might have further degraded their already limited walking-adaptability performance.

Table II. Mean normal-gait and walking-adaptability outcomes and results of the 2-way analysis of variance (ANOVA)

	Mean values				Effects					
	Polio survivors		Healthy individuals		Time		Group		Time × Group	
Normal walking	*First minute*	*Sixth minute*	*First minute*	*Sixth minute*	*F(1,52)*	*p-value*	*F(2,51)*	*p-value*	*F(2,51)*	*p-value*
Mean step time (s)	0.73 (0.10) 0.65 (0.12)	0.74 (0.12) 0.65 (0.11)	0.59 (0.05)	0.61 (0.06)	3.1	0.083	6.3	**0.004**	1.0	0.389
Variability in step time (s)	0.05 (0.07) 0.05 (0.09)	0.06 (0.08) 0.04 (0.02)	0.02 (0.01)	0.02 (0.01)	0.0	0.934	0.2	0.811	1.0	0.361
					F(1,31)	*p-value*	*F(1,30)*	*p-value*	*F(1,30)*	*p-value*
Mean step width (cm)	18.1 (6.8)	18.2 (6.7)	14.8 (3.0)	14.9 (3.4)	0.8	0.682	0.0	0.922	0.0	0.967
Variability in step width (cm)	0.02 (0.01)	0.03 (0.01)	0.02 (0.01)	0.02 (0.01)	2.8	0.102	0.5	0.492	0.2	0.667
Target stepping	*First minute*	*Sixth minute*	*First minute*	*Sixth minute*	*F(1,52)*	*p-value*	*F(1,51)*	*p-value*	*F(1,51)*	*p-value*
Variable error (mm)	34.2 (10.2) 34.1 (8.0)	37.4 (9.3) 38.7 (8.9)	37.6 (6.7)	40.9 (7.1)	8.0	**0.007**	0.32	0.727	0.17	0.848
Narrow-beam walking	*First minute*	*Sixth minute*	*First minute*	*Sixth minute*	*F(1,32)*	*p-value*	*F(1,32)*	*p-value*	*F(1,32)*	*p-value*
Mean step width (cm)	10.5 (5.7)	11.7 (6.5)	4.0 (1.9)	3.5 (1.5)	1.2	0.283	15.5	**< 0.001**	6.7	**0.014**

For step time and variable error (VE), the upper mean values represent polio survivors' most affected leg, while the lower mean values represent polio survivors' least affected leg. For healthy individuals, the mean values over the left and right leg are shown. Significant effects ($p < 0.05$) are shown in **bold**.

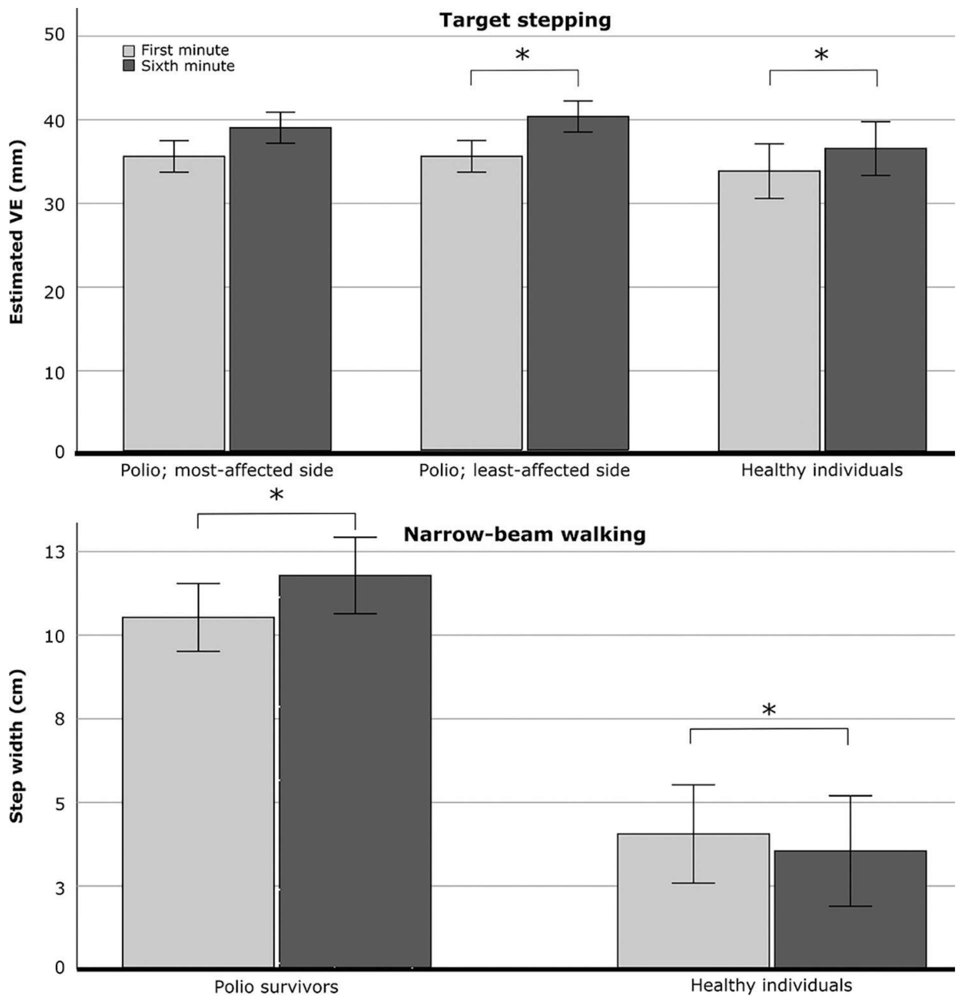

Fig. 4. Walking-adaptability outcomes. Target-stepping performance (*upper panel*) for polio survivors' most- and least-affected leg ($n=22$) and healthy individuals ($n=11$), as visualized by the estimated variable error (VE, in mm) at 0.69 m/s, and narrow-beam walking performance (*lower panel*) for polio survivors ($n=23$) and healthy individuals ($n=11$), visualized as step width (cm). *Error bars* represent the standard error of the mean. $^*p<0.05$.

Cardiorespiratory fatigue increased significantly after 6-min walking for both polio survivors and healthy individuals. For healthy individuals, the increases in both HR and RPE were only modest and the absolute values represent low-to-moderate physical intensity (23). The observed substantial increases in HR and RPE in polio survivors indicate that 6-min walking was more demanding for them than for healthy individuals (Fig. 3), probably explained by their increased energy cost of walking, which is highly correlated with reduced leg-muscle strength (4).

Adaptive walking was more demanding than normal walking, as evidenced by higher cardiorespiratory fatigue and higher muscle activation. During adaptive walking, participants adjusted their gait pattern to external cues, which probably increased energy demands (28) and accelerated fatigue development. However, in contrast to our expectations, muscle activity reduced rather than increased during both walking-adaptability tests in polio survivors and during narrow-beam walking in healthy individuals. One explanation for these findings might be that the occurrence of fatigue prioritizes a reduction in muscle activation over task performance. According to the Borg scores, physical intensity was almost maximal in 17% of polio survivors during target stepping and in 43% of polio survivors during narrow-beam walking (i.e. Borg-score > 16; perceived exertion rated as hard to very hard (29)). This might suggest near-maximal neural drive, in which case motor-unit recruitment and firing rate could not be increased to compensate for fatigue, leading to a reduction in force output and a decrease in RMS amplitudes (30). Another explanation for the decline in muscle activity in polio survivors might be impaired voluntary muscle activation (31), which may become even more limited when fatigued (8). As a result, RMS amplitudes would decrease and force output would reduce. Ultimately, a reduction in force output may hamper the ability to adapt the walking pattern to external cues, which might explain the decrease in walking-adaptability performance in the polio survivors.

In the healthy individuals, muscle activation did not change during target stepping while test performance decreased. Given the relatively low HR and RPE, it seems unlikely that their test performance was affected by cardiorespiratory fatigue. The target-stepping task was a rather monotone task, which could have led to a reduction in concentration and consequently a decline in task performance. During narrow-beam walking, we tried to avoid boredom by changing the width of the beam every minute. In this task, the reduction in muscle activation was accompanied by an improvement in task performance (i.e. narrower steps). It is possible that healthy individuals managed to optimize their gait pattern during narrow-beam walking, enabling them to improve task performance while reducing muscle activity from the first to the sixth minute of the test (32).

During narrow-beam walking, polio survivors were forced to narrow their steps compared with normal walking (Table II), which probably became too difficult to sustain when fatigued, as indicated by their decline in test performance. Step width may have been increased to maintain mediolateral stability at the expense of a poorer task performance (33). Also, for target stepping, despite the non-significant group-effect, the reduction in performance tended to be more pronounced for polio survivors' least affected leg (Fig. 4), which might be explained by increasing balance impairments when the most-affected leg serves as the stance leg (34). Altogether, these findings suggest that walking-induced fatigue increases balance impairments in polio survivors, which further degrades their already limited walking adaptability (17) and contributes to their high fall risk.

Study limitations and strengths

This study has some limitations. Due to COVID-19 restrictions, it was not possible to include the intended number of participants, which hampered full counterbalancing of the test orders. Furthermore, since walking is a daily-life activity during which polio survivors often fall, we strengthened the clinical relevance of this study by investigating walking-induced fatigue, rather than fatigue resulting from isolated muscle contractions. For polio survivors, walking at a comfortable speed probably requires a higher proportion of their maximal muscle strength, while healthy individuals may have spare capacity (35). Since we did not record maximal voluntary muscle contractions, we were unable to compare the relative muscle activation during walking between the 2 groups. However, we were able to compare normal and adaptive walking, and the results demonstrate that adaptive walking at a self-selected, fixed speed on a treadmill is more demanding than normal walking, especially in polio survivors.

Although the findings of this study are based on a relatively small study sample, they emphasize the merit of evaluating the effects of fatigue on walking adaptability, which, in comparison with normal walking, reflects certain challenges of walking in daily life.

CONCLUSION

The results of this study indicate that prolonged walking is more fatiguing for polio survivors than for healthy individuals and that adaptive walking is more fatiguing than normal walking. Walking-adaptability performance declined after 6 min, especially in polio survivors during narrow-beam walking. Six minutes adaptive walking may thus induce fatigue in polio survivors, which further degrades their already limited walking-adaptability performance. Since this might increase the fall risk among polio survivors, these findings have practical implications for fall-risk management within this population. The results of this study should be confirmed in a future study with a larger study sample.

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The authors have no conflicts of interest to declare.

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