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Published in:
NeuroRehabilitation

DOI:
10.3233/NRE-130978

2013

Muscle strength is only a weak to moderate predictor of gait performance in persons with late effects of polio

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Short title: Muscle strength and gait performance in post-polio

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ABSTRACT

Objective: To assess muscle strength in the knee extensors, knee flexors and ankle dorsiflexors in persons with late effects of polio, and determine how much muscle strength, gender, age and BMI are related to gait performance

Methods: Ninety community-dwelling ambulant persons (47 men and 43 women; mean age 64 years SD 8) with late effects of polio participated. Isokinetic concentric knee extensor and flexor muscle strength was measured at 60º/s and ankle dorsiflexor muscle strength at 30º/s. Gait performance was assessed by the Timed "Up & Go", the Comfortable and Fast Gait Speed tests, and the 6-Minute Walk test.

Results: There were significant correlations between knee extensor and flexor muscle strength and gait performance ($p<0.01$), and between ankle dorsiflexor muscle strength and gait performance ($p<0.05$), for both lower limbs. Muscle strength in the knee extensors and flexors explained 7% to 37% and 9% to 47%, respectively, of the variance in gait performance. Strength in the ankle dorsiflexors explained 4% to 24%, whereas gender, age and BMI contributed at most an additional 9%.

Conclusion: Knee muscle strength, and to some extent ankle dorsiflexor muscle strength, are predictors of gait performance in persons with late effects of polio, but the strength of the relationships indicates that other factors are also important.

Key words: Post poliomyelitis syndrome, gait, muscle strength

Several years after an acute paralytic poliomyelitis infection new symptoms – referred to as late effects of polio or post-polio syndrome – can occur (Farbu et al., 2006; Halstead, Gawne, & Pham, 1995; Trojan & Cashman, 2005). Common symptoms are muscle weakness, muscle fatigue, general fatigue, pain during activity and cold intolerance (Lexell & Brogårdh, 2012). Muscle weakness in the lower limbs in persons with late effects of polio can lead to increasing walking difficulties, both objectively measured and self-reported (Brehm, Beelen, Doorenbosch, Harlaar, & Nollet, 2007; Brogårdh, Flansbjer, Espelund, & Lexell, 2013; Hachisuka, Makino, Wada, Saeki, & Yoshimoto, 2007; Perry, Mulroy, & Renwick, 1993), which can impact on everyday activities and restrict participation (Grimby & Jonsson, 1994; Ivanyi et al., 1999; Nollet et al., 1999; Thoren-Jonsson, 2000; Willen, Thoren-Jonsson, Grimby, & Sunnerhagen, 2007).

To be able to plan appropriate rehabilitation interventions, it is important to understand how different factors influence gait performance. Several studies have described a moderate to strong relationship between knee muscle strength and walking ability in persons with different neurological diseases (Flansbjer, Downham, & Lexell, 2006; Thoumie & Mevellec, 2002; Willen, Sunnerhagen, Ekman, & Grimby, 2004). Some studies have reported a similar relationship between lower limb muscle strength and gait performance in persons with late effects of polio (Brehm, Nollet, & Harlaar, 2006; Gylfadottir, Dallimore, & Dean, 2006; Perry, et al., 1993; Willen, et al., 2004), but the results differ as different outcome measurements and statistical analyses were used. Two studies reported that isometric muscle strength in the hip, knee and ankle muscles contributed 14% to 59% to the variance in gait performance (Gylfadottir, et al., 2006; Perry, et al., 1993). Willén et al. 2004 pooled the lower limb muscle strength into an index and reported a non-linear relationship between walking speed and muscle strength, and also that Body Mass Index (BMI) was related to walking ability. In healthy persons, age, gender and BMI are related to muscle strength and walking ability (Enright & Sherrill, 1998; Porter, Vandervoort, & Lexell, 1995) and therefore these variables should be taken into account when the relationship between muscle strength and gait performance in persons with late effects of polio is assessed. Furthermore, no study has investigated how separate muscle groups in the lower limb are related to the gait performance. This knowledge could assist clinicians to design more targeted rehabilitation interventions in persons with late effects polio.

The aim of this study was to assess muscle strength in the knee extensors, knee flexors and ankle dorsiflexors in persons with late effects of polio, and determine how much muscle strength, gender, age and BMI are related to gait performance

Methods

Participants

Ninety community-dwelling persons (47 men and 43 women), able to walk at least 200 m with or without an assistive and/or orthotic device, were recruited from a post-polio rehabilitation clinic in a university hospital in the south of Sweden. Their mean age was 64 years (SD 8, 32-80 years) and the mean time since onset of new symptoms was 14 years (SD 7, 2-47 years). All participants met the criteria of postpoliomyelitis syndrome, as defined by Halstead and Rossi (Halstead & Rossi, 1985). They had all a confirmed history of acute poliomyelitis affecting the lower limbs, new symptoms after a period of functional stability, and no other diseases that could explain their reduced muscle strength. An electromyogram (EMG) had been recorded in the lower limbs (vastus medialis and tibialis anterior muscles) as part of the initial routine clinical examination and verification of prior polio. Following the National Rehabilitation Hospital (NRH) Post-Polio Limb Classification (Halstead, et al., 1995) and the participants' own perception of their post-polio, one lower limb was defined as the "less affected" limb and the other as the "more affected". All persons had post-polio NRH class III-V (indicating clinically stable, clinically unstable or severely atrophic polio) in at least one lower limb. All participants' height and weight were recorded to calculate their body mass index (BMI). Prior to inclusion, information about the purpose of the study was provided, and each participant gave their written informed consent to participate. The study followed the principles of the Helsinki declaration.

Testing and procedure

All assessments were performed at a university hospital by three senior physiotherapists. The total time for the assessments was approximately two hours. The test sessions started with the isokinetic strength measurements and were followed by the four gait performance tests (see below). A test protocol was carefully followed for all participants: i.e., the same time interval between the tests, the same commands and the same environment.

Muscle strength measurements

Isokinetic concentric knee extensor, knee flexor and ankle dorsiflexor muscle strength were measured with a Biodex® Multi-Joint System 3 PRO dynamometer using a standard protocol, previously applied in our research group (Flansbjer, Drake, & Lexell, 2011; Flansbjer & Lexell, 2010b). These studies have shown that lower limb muscle strength can be reliably measured in persons with late effects of polio. For the knee extensors and flexors, the intraclass correlation coefficient ($ICC_{2,1}$) was 0.85 to 0.99 and the standard error of measurement (SEM) was 10.2 Nm to 13.9 Nm (Flansbjer & Lexell, 2010b). For the ankle dorsiflexors, the $ICC_{2,1}$ was 0.85 to 0.99 and the SEM 2.5 to 3.7 Nm (Flansbjer, et al., 2011).

Before each measurement the full range of motion (ROM) was set and the Biodex software applied the gravity correction. Consistent verbal encouragement was given throughout. The knee extensors and flexors in the less affected lower limb were measured firstly, followed by the ankle dorsiflexors. The order of measurement was then repeated in the more affected lower limb.

For the knee muscle strength measurements, the participants were seated in the adjustable chair of the dynamometer without shoes or orthotic device, and were stabilised with straps across the shoulders, waist and thigh. After a structured warm-up they performed three maximal isokinetic extensor and flexor muscle contractions at 60°/s, and the highest peak torques were recorded (Newton meter; Nm). For the ankle dorsiflexor muscle strength measurements, the participants were seated in the adjustable chair of the dynamometer, with the leg to be tested elevated by a support arm just above the knee with the angles of the hip (90º flexion) and the knee joint (30º flexion). The ankle was placed and secured on the Biodex footplate. To warm-up and become familiar with the ankle measurements, three to five sub-maximal contractions with the dorsiflexor muscles were performed. After a one-minute rest, three maximal contractions at 30º/s were performed, with 30 seconds rest between each contraction. Each contraction started from a relaxed plantar flexed position without any preload and the highest peak torques were recorded (Newton meter; Nm). Due to weakness and/or stiffness, 5 persons were unable to perform the knee muscle strength measurements in the more affected lower limb, 53 persons were unable to perform the ankle dorsiflexor muscle strength measurements in the more affected lower limb and 9 persons in the less affected lower limb. The muscle strength for these measurements was scored as “0” in the statistical analyses.

Gait performance tests

After a 20 minutes rest, all 90 participants then completed four gait performance tests: the Timed “Up & Go” test (TUG), the 10 meter Comfortable and the 10 meter Fast Gait Speed tests (CGS and FGS), and the 6-Minute Walk test (6MW). These tests have been shown to be reliable in persons with late effects of polio (ICC2,1 0.82-0.97; SEM% 4% to 7%) (Flansbjer & Lexell, 2010a). All subjects were allowed to use, if needed, their assistive and/or orthotic device during the tests. A digital stopwatch with an accuracy of one decimal figure in units of 1 sec was used to measure time. All tests were performed in a 2.2 m wide corridor with a linoleum floor in a quiet part of the hospital.

The TUG (Podsiadlo & Richardson, 1991) was developed primarily to evaluate basic functional mobility in frail elderly persons and has been used as an outcome measure in persons with late effects of polio (Brogårdh, Flansbjer, & Lexell, 2010; Lehmann, Sunnerhagen, & Willen, 2006). For the TUG, the participants sat in an arm chair placed at the end of a marked 3-m walkway. They were instructed to sit with their back against the chair and on the word “go”, stand up, walk at a comfortable speed passed the 3-m mark, turn around, walk back and sit down in the chair. Each participant did one trial to become familiar with the test, and then performed the TUG twice with a one-min rest between each trial. The time from the start until they sat down in the chair with back support was measured and the mean of the two tests was recorded. All participants were allowed, if needed, to use the armrests for support when raising and sitting down.

Gait speed timed over short distances (mostly 5 to 10 m) has been used to assess mobility in persons with late effects of polio (Brehm, et al., 2006; Horemans, Bussmann, Beelen, Stam, & Nollet, 2005; Willen, et al., 2007). For the CGS and FGS, a 14-meter walkway was marked at the floor and the participants were timed over the middle 10 meter. For the CGS, the participants were told to walk at a self-selected comfortable pace, whereas for the FGS they were told to walk as fast and safely as possible without running. The test session started with the CGS three times in succession and with 30 s between each trial. After a further 30 s rest, the test session continued with the FGS, also three times in succession, with 30 s between each trial. The time taken to walk 10 meter was recorded (in seconds) for each trial and the mean value was calculated for CGS and FGS, respectively.

The 6MW is regarded as a sub-maximal test of aerobic capacity and was originally used to assess patients with cardiovascular or cardio-respiratory problems (Bittner et al., 1993).

The test has also been used as an outcome measure after an intervention in persons with late effects of polio (Brogårdh, et al., 2010; Gylfadottir, et al., 2006). The participants were instructed to walk 30 meter between two marks on the floor, and, after passing either mark, turn and walk back. They were told to walk as far as possible during six minutes, and were informed when three minutes of the test remained, but no other verbal encouragement was given during the test. The 6MW was performed once and the numbers of 30 meter lengths were counted. In addition, every meter was marked on the wall, so the distance walked could be measured to the nearest meter.

Statistical analyses

Descriptive statistics (mean ± SD) were calculated for the participant characteristics. The paired sample t-test was used to determine differences between the muscle strength in the more affected and the less affected lower limbs. The relationships between the muscle strength measurements and the gait performance tests were analyzed with the Pearson's correlation coefficients (r).

To analyze how much of the gait performance that could be explained by the muscle strength in the different muscle groups in the lower limbs, and to determine the possible influence of the participants' gender, age and BMI, linear regression analyses were applied. The four gait performance tests were the dependent variables and the six strength measurements were the independent variables in the first step. As there were significant correlations between the knee extensor and flexor muscle strength measurements ($r= 0.75$ to 0.76; $p<0.01$), and between the knee muscle strength measurements and the ankle dorsiflexor muscle strength measurements ($r=0.51$ to 0.54; $p<0.01$) in each lower limb, the different strength measurements were analysed separately. The variables for the more and less affected lower limbs were first entered in the model, separately as well as simultaneously. In the next step, the other independent variables (gender, age and BMI) were added in the analyses.

The R^2 value represents the proportionate contribution of the independent variables to the variance of the dependent variable, and the adjusted R^2 value was used here to correct for multiple variables. The suitability of this approach – the aptness of the linear model and the normality of the residuals – was addressed in scatter-plots of the residuals and predicted values, in normal probability plots, in Q-Q plots and One-Sample Kolmogorov-Smirnov tests, and the normality assumptions were never rejected.

Statistical significance levels were based on the hypothesis that the values of the coefficients are zero. All calculations were performed using the IBM SPSS Statistics Software version 20.0. Significance levels below 0.05 represent statistical significance.

Results

Out of the 90 participants, 21 individuals walked with an ankle foot orthosis (AFO), 17 individuals used a walking aid, and their mean BMI was 26.6 (SD 3.5, 18.5–36.6). The summary statistics of the knee extensor and flexor muscle strength, the ankle dorsiflexor muscle strength and the gait performance tests for the 90 participants are presented in Table 1. Muscle strength in the more affected lower limb was significantly lower ($p<0.001$) than in the less affected lower limb for both the knee extensors, knee flexors and ankle dorsiflexors. The differences in muscle strength between the two lower limbs were not related to gender, age or BMI.

Insert Table 1 about here

The correlation coefficients (Pearson's r) between muscle strength and gait performance, the significance levels and a summary of the results of the linear regression analyses (adjusted R^2) are presented in Table 2. Both knee extensor and flexor muscle strength ($r= -0.28$ to $r=65$; $p<0.01$), and ankle dorsiflexor muscle strength ($r= -0.22$ to $r=0.49$; $p<0.05$), were significantly related to gait performance, except for knee extension and ankle dorsiflexion for the less affected lower limb for TUG ($r=-0.18$ to -0.19; $p=0.05$-0.10).

Muscle strength in the knee extensors and flexors explained 7% to 37% and 9% to 47%, respectively, of the variance in gait performance. Knee muscle strength, in particular knee flexor strength, explained more of the variance in FGS and 6MW than in CGS and TUG. The ankle dorsiflexor muscle strength in the more affected and the less affected lower limb explained 4 to 24% of the variance in gait performance. When the other independent variables (gender, age and BMI) were added in the multiple regression analyses, they contributed at most an additional 9% to the variance in gait performance.

Insert Table 2 about her

Discussion

In this study we have assessed muscle strength in the knee extensors, knee flexors and ankle dorsiflexors in persons with late effects of polio, and determined how much muscle strength, gender, age and BMI are related to gait performance. The main findings were that knee muscle strength and ankle dorsiflexor strength were significantly related to gait performance. Knee muscle strength had the largest influence, especially on faster gait speed and gait endurance, whereas gender, age, and BMI had only a small influence on gait performance.

Knowledge about the relationship between muscle strength and gait performance is important as it can assist in the planning of rehabilitation interventions. Progressive muscular weakness is a common impairment in persons with various diseases in the nervous system, and is directly related to the loss of functioning motor neurons which appears as part of the progression of late effects of polio (Trojan & Cashman, 2005). Since muscle strength is of importance for daily activities and for independence and autonomy (Lexell, 2000), measurement of lower limb muscle strength and interventions aiming at improving muscle strength, are important components in rehabilitation. One method to assess muscle strength in clinical settings and in research is isokinetic dynamometry (Lexell, Flansbjer, & Brogårdh, 2012). Manual muscle testing or isometric measurements using handhold dynamometers have previously been the most common way to measure muscle strength (Stark, Walker, Phillips, Fejer, & Beck, 2011), and handhold dynamometers is still recommended in clinical settings. For research purposes isokinetic dynamometers provide more detailed results and several studies have described the relationship between muscle strength and walking ability in persons with different neurological diseases, such as multiple sclerosis, late effects of polio and stroke (Flansbjer, et al., 2006 ; Thoumie & Mevellec, 2002; Willen, et al., 2004).

Our findings of a moderate relationship overall between muscle strength in the lower limb and gait performance are in agreement with other studies (Brehm, et al., 2006; Gylfadottir, et al., 2006; Perry, et al., 1993; Willen, et al., 2004). However, the results from those studies are not quite comparable to the results in the present study. The measurement tools used to assess strength and gait performance have varied and no study has specifically analysed the influence of muscles around the knee and ankle joints, separately, on gait performance. We found that muscle strength in the knee extensors and knee flexors, rather than the strength in the ankle dorsiflexors, is a predictor for gait performance in persons with late effects of polio. Another study, using isokinetic dynamometry, combined the strength measurements into a strength index which makes it difficult to fully compare the results (Willen, et al., 2004). For CGS the strength index explained 46% of the variance and for FGS 57% of the variance, and both gender and BMI influenced gait performance. The results of that study (Willen, et al., 2004) indicate that muscle strength has a larger influence on faster walking speeds, in agreement with our results. In another study the muscle strength from both lower limbs was measured by a tensiometer (Perry, et al., 1993). The authors reported that the mean plantar flexion torque was the best predictor for gait performance, explaining 58% of the variance and that knee extension only explained 18% of the variation, which is much lower than in our study. In one study muscle strength was measured by a handhold dynamometer (Gylfadottir, et al., 2006) and the muscle strength measurements were combined into a global score. Balance and pre-test pain were strong predictors of walking ability and only 14% of the distance walked during the 6MW test could be explained by muscle strength. In one study (Brehm, et al., 2006), a summation of muscle strength for 8 muscles in the lower limb explained 59% of walking speed.

To be able to assess how much muscle strength in the different muscle groups influenced gait performance, a linear regression model was used in the present study. Previous studies have used a non-linear model as the relationship between muscle strength and gait performance is reported to be curvilinear in older individuals (Buchner, Larson, Wagner, Koepsell, & de Lateur, 1996) as well as in persons with late effects of polio (Willen, et al., 2004). This means that if muscle strength is below a minimum needed to walk, or above a muscle strength sufficient for normal walking, any change in muscle strength will affect the physiological reserve but not gait speed (Buchner, et al., 1996). We choose the linear regression model since all individuals reported muscle weakness but were able to walk at least 200 m. We controlled the aptness of this model in several ways and the suitability was never rejected, thus, confirming that the linear model could be applied for our sample.

As the strength measurements in the knee and ankle dorsiflexor muscles were highly correlated, the analyses were performed in two steps, with the strength measurements analyzed both separately and simultaneously. In general, higher correlations were found between the more affected lower limb and gait performance than for the less affected lower limb, and the correlations were highest for the faster gait speed test and tests of gait endurance. The gait performance test with the lowest correlation to muscle strength was TUG. One explanation might be that TUG measures somewhat other dimension of gait performance, such as rising, sitting down and turning around, rather than just plain walking.

Furthermore, in TUG the participants were allowed to use their hands when rising and sitting down, which could have influenced the results, especially for the knee extensor strength. Taken together, our results indicate that muscle strength is a weak to moderate predictor of gait performance in persons with late effects of polio.

As other factors than muscle strength can influence gait performance (*International Classification of Functioning, Disability and Health: ICF* 2001), different independent variables were used in the linear regression model. Gender was included as one variable to explain any differences between the men and the women regarding strength. Age and BMI were also included because they have been shown to be related to muscle strength and gait performance in healthy people (Porter, et al., 1995) and in persons with late effects of polio (Willen, et al., 2004). However, in our study these factors only explained at most an additional 9% of the variance in gait performance, and it was obvious that muscle strength in the more affected lower limb had the largest influence on the variance in gait performance.

We found that knee muscle strength, in particular the flexors, was related to gait speed and gait endurance, as assessed by FGS and 6MW. The importance of strength in the knee flexor muscles for faster gait speed has also been reported in persons with multiple sclerosis (Thoumie & Mevellec, 2002) and in persons with chronic stroke (Flansbjer, Lexell, & Brogårdh, 2012), explaining up to 50% the gait performance. The importance of the knee flexors for gait performance in persons with late effects of polio implies that increasing strength in these muscles might improve gait speed and gait endurance, which could be of benefit in their performance of daily activities.

Two factors could have affected the results of this study: the reliability of the measurements and the sample size. However, the muscle strength measurements and the gait performance tests used in this study have been shown to be highly reliable (Flansbjer, et al., 2011; Flansbjer & Lexell, 2010a, 2010b) and the sample size could be considered large enough to be able to make the inferences. The participants were selected from a post-polio clinic; they were all community-dwelling and ambulant and had a verified post-polio class III-V. They had previously participated in the clinics' rehabilitation program and were knowledgeable of the rehabilitation team. The participants represented a wide spread of functioning; some had very weak muscles but were still able to walk at least 200 m. Their mean age was similar to the total sample in the database, but the results from this study can only be generalized to individuals with similar age and degree of post-polio related disability. A limitation is that more than half of the participants scored "0" in at least one of their dorsiflexors, as they had no measureable strength in these muscles, particularly in the more affected lower limb. However, as they used their ordinary walking aids and ankle-foot orthoses when walking, this probably provided appropriate compensation for the lack of strength during the gait performance tests. Another limitation is that only the knee extensors, knee flexors and ankle dorsiflexors strength were measured. These muscle groups were chosen as they are important for gait performance and measurements of these muscles are reliable in persons with late effect of polio (Flansbjer, et al., 2011; Flansbjer & Lexell, 2010a, 2010b). Weakness in hip and ankle plantar flexors can also influence gait performance in persons with late effects of polio, and should be measured in future studies.

Conclusion

Knee extensor and flexor muscle strength, and to some extent ankle dorsiflexor muscle strength, are predictors of gait performance in persons with late effects of polio. Knee flexor strength seemed to be more important than knee extensors for both speed and endurance, whereas gender, age, and BMI did only marginally influence gait performance. These findings imply that improving muscle strength may only partly improve gait performance in persons with late effects of polio, and that other factors are important.

Declaration of interest

None.

Acknowledgement

The study was prepared within the context of the Centre for Ageing and Supportive Environments (CASE) at Lund University, funded by the Swedish Research Council for Working Life and Social Research, and had received financial support from the Swedish Association of Survivors of Traffic Accidents and Polio (RTP), Stiftelsen för bistånd åt rörelsehindrade i Skåne and Skane county council’s research and development foundation.

References

Bittner, V., Weiner, D. H., Yusuf, S., Rogers, W. J., McIntyre, K. M., Bangdiwala, S. I., et.al. Bourassa, M. G. (1993). Prediction of mortality and morbidity with a 6-minute walk test in patients with left ventricular dysfunction. SOLVD Investigators. *Jama, 270*, 1702-1707.

Brehm, M. A., Beelen, A., Doorenbosch, C. A., Harlaar, J., & Nollet, F. (2007). Effect of carbon-composite knee-ankle-foot orthoses on walking efficiency and gait in former polio patients. *J Rehabil Med, 39*, 651-657.

Brehm, M. A., Nollet, F., & Harlaar, J. (2006). Energy demands of walking in persons with postpoliomyelitis syndrome: relationship with muscle strength and reproducibility. *Arch Phys Med Rehabil, 87*, 136-140.

Brogårdh, C., Flansbjer, U. B., Espelund, C., & Lexell, J. (2013). Relationship between self-reported walking ability and objectively assessed gait performance in persons with late effects of polio. *NeuroRehabilitation*, In press.

Brogårdh, C., Flansbjer, U. B., & Lexell, J. (2010). No effects of whole-body vibration training on muscle strength and gait performance in persons with late effects of polio: a pilot study. *Arch Phys Med Rehabil, 91*, 1474-1477.

Buchner, D. M., Larson, E. B., Wagner, E. H., Koepsell, T. D., & de Lateur, B. J. (1996). Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing, 25*, 386-391.

Enright, P. L., & Sherrill, D. L. (1998). Reference equations for the six-minute walk in healthy adults. *Am J Respir Crit Care Med, 158*, 1384-1387.

Farbu, E., Gilhus, N. E., Barnes, M. P., Borg, K., de Visser, M., Driessen, A., et.al. Stalberg, E. (2006). EFNS guideline on diagnosis and management of post-polio syndrome. Report of an EFNS task force. *Eur J Neurol, 13*, 795-801.

Flansbjer, U. B., Downham, D., & Lexell, J. (2006). Knee muscle strength, gait performance, and perceived participation after stroke. *Arch Phys Med Rehabil, 87*, 974-980.

Flansbjer, U. B., Drake, A. M., & Lexell, J. (2011). Reliability of ankle dorsiflexors strength measurements in persons with late effects of polio. *Isokinet Exerc Sc, 19*, 55-61.

Flansbjer, U. B., & Lexell, J. (2010a). Reliability of gait performance tests in individuals with late effects of polio. *PM R, 2*, 125-131.

Flansbjer, U. B., & Lexell, J. (2010b). Reliability of knee extensor and flexor muscle strength measurements in persons with late effects of polio. *J Rehabil Med, 42*, 588-592.

Flansbjer, U. B., Lexell, J., & Brogårdh, C. (2012). Isokinetic knee extensor and flexor muscle strength in individuals with hemiparesis after stroke. *Isokinet Exerc Sc 20*, 91-97.

Grimby, G., & Jonsson, A. L. (1994). Disability in poliomyelitis sequelae. *Phys Ther, 74*, 415-424.

Gylfadottir, S., Dallimore, M., & Dean, E. (2006). The relation between walking capacity and clinical correlates in survivors of chronic spinal poliomyelitis. *Arch Phys Med Rehabil, 87*, 944-952.

Hachisuka, K., Makino, K., Wada, F., Saeki, S., & Yoshimoto, N. (2007). Oxygen consumption, oxygen cost and physiological cost index in polio survivors: a comparison of walking without orthosis, with an ordinary or a carbon-fibre reinforced plastic knee-ankle-foot orthosis. *J Rehabil Med, 39*, 646-650.

Halstead, L. S., Gawne, A. C., & Pham, B. T. (1995). National rehabilitation hospital limb classification for exercise, research, and clinical trials in post-polio patients. *Ann N Y Acad Sci, 753*, 343-353.

Halstead, L. S., & Rossi, C. D. (1985). New problems in old polio patients: results of a survey of 539 polio survivors. *Orthopedics, 8*, 845-850.

Horemans, H. L., Bussmann, J. B., Beelen, A., Stam, H. J., & Nollet, F. (2005). Walking in postpoliomyelitis syndrome: the relationships between time-scored tests, walking in daily life and perceived mobility problems. *J Rehabil Med, 37*, 142-146.

International Classification of Functioning, Disability and Health: ICF (2001). World Health Organization.

Ivanyi, B., Nollet, F., Redekop, W. K., de Haan, R., Wohlgemuht, M., van Wijngaarden, J. K., & de Visser, M. (1999). Late onset polio sequelae: disabilities and handicaps in a population-based cohort of the 1956 poliomyelitis outbreak in The Netherlands. *Arch Phys Med Rehabil, 80*, 687-690.

Lehmann, K., Sunnerhagen, K. S., & Willen, C. (2006). Postural control in persons with late effects of polio. *Acta Neurol Scand, 113*, 55-61.

Lexell, J. (2000). Muscle structure and function in chronic neurological disorders: the potential of exercise to improve activities of daily living. *Exerc Sport Sci Rev, 28*, 80-84.

Lexell, J., & Brogardh, C. (2012). Life satisfaction and self-reported impairments in persons with late effects of polio. *Ann Phys Rehabil Med, 55*, 577-589.

Lexell, J., Flansbjer, U.-B., & Brogårdh, C. (2012). Isokinetic assessment of muscle function: Our experience with patients afflicted with selected diseases in the nervous system. *Isokinet Exerc Sc, 20*, 267-273

Nollet, F., Beelen, A., Prins, M. H., de Visser, M., Sargeant, A. J., Lankhorst, G. J., & de Jong, B. A. (1999). Disability and functional assessment in former polio patients with and without postpolio syndrome. *Arch Phys Med Rehabil, 80*, 136-143.

Perry, J., Mulroy, S. J., & Renwick, S. E. (1993). The relationship of lower extremity strength and gait parameters in patients with post-polio syndrome. *Arch Phys Med Rehabil, 74*, 165-169.

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc, 39*, 142-148.

Porter, M. M., Vandervoort, A. A., & Lexell, J. (1995). Aging of human muscle: structure, function and adaptability. *Scand J Med Sci Sports, 5*, 129-142.

Stark, T., Walker, B., Phillips, J. K., Fejer, R., & Beck, R. (2011). Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. *PM R, 3*, 472-479.

Thoren-Jonsson, A. L. (2000). *Adaptation and ability in daily occupations in people with poliomyelitis sequelae.* PhD, University of Gothenburg, Gothenburg.

Thoumie, P., & Mevellec, E. (2002). Relation between walking speed and muscle strength is affected by somatosensory loss in multiple sclerosis. *J Neurol Neurosurg Psychiatry, 73*, 313-315.

Trojan, D. A., & Cashman, N. R. (2005). Post-poliomyelitis syndrome. *Muscle Nerve*, *31*, 6-19.

Willen, C., Sunnerhagen, K. S., Ekman, C., & Grimby, G. (2004). How is walking speed related to muscle strength? A study of healthy persons and persons with late effects of polio. *Arch Phys Med Rehabil, 85*, 1923-1928.

Willen, C., Thoren-Jonsson, A. L., Grimby, G., & Sunnerhagen, K. S. (2007). Disability in a 4-year follow-up study of people with post-polio syndrome. *J Rehabil Med, 39*, 175-180.

Table 1: Summary of the isokinetic strength measurements and the gait performance tests for the 90 participants

	Mean	SD	Range
Isokinetic strength measurements			
Knee extension 60º/s (Nm)			
Less affected	104.5	43.8	15.2–198.8
More affected	68.4	45.7	0.0–185.5
Knee flexion 60º /s (Nm)			
Less affected	55.3	24.2	1.7–123.2
More affected	35.3	24.1	0.0–105.0
Ankle dorsiflexion 30º/s (Nm)			
Less affected	22.9	11.3	0.0–48.6
More affected	8.7	12.2	0.0–48.5
Gait performance tests			
Timed Up & Go (s)	10.8	2.7	6.9–22.5
Gait Speed (m/s)			
Comfortable	1.1	0.2	0.6–1.6
Fast	1.6	0.3	0.8–2.9
6-Minute Walk (m)	431	95	186–699

Nm=Newton meter; s=seconds; m=meter;

Table 2: Relationships between the isokinetic muscle strength measurements and the gait performance tests (Pearson's r), and the results of the multiple linear regression analyses (Adjusted R^2)

	TUG (s)	CGS (m/s)	FGS (m/s)	6MW (m)
Knee Extension 60º/s				
More affected (r)	-0.31**	-0.47**	-0.54**	0.57**
Less affected (r)	-0.19^{ns}	-0.35**	-0.39**	0.51**
More affected (Adjusted R^2)	0.08	0.21	0.29	0.32
More and less affected (Adjusted R^2)	0.07	0.21	0.29	0.37
More and less affected, Gender, Age and BMI (Adjusted R^2)	0.09	0.24	0.34	0.42
Knee Flexion 60º/s				
More affected (r)	-0.28**	-0.48**	-0.59**	0.65**
Less affected (r)	-0.30**	-0.45**	-0.49**	0.58**
More affected (Adjusted R^2)	0.07	0.23	0.35	0.42
More and less affected (Adjusted R^2)	0.09	0.26	0.37	0.47
More and less affected, Gender, Age and BMI (Adjusted R^2)	0.11	0.25	0.41	0.53
Ankle dorsiflexion 30°/s				
More affected (r)	-0.22*	-0.39**	-0.46**	0.49**
Less affected (r)	-0.18^{ns}	-0.24*	-0.29**	0.32**
More affected (Adjusted R^2)	0.04	0.14	0.20	0.23
More and less affected (Adjusted R^2)	0.04	0.14	0.21	0.24
More and less affected, Gender, Age and BMI (Adjusted R^2)	0.05	0.22	0.27	0.33

** $p<0.01$, *$p<0.05$, ^{ns} not significant;

s=seconds; m=meter; TUG=Timed Up & Go; CGS=Comfortable Gait Speed; FGS=Fast Gait Speed; 6MW=6-Minute Walk; BMI=Body Mass Index