Scand J Rehab Med 27: 183–192, 1995

# A COMPARISON OF SYMPTOMS BETWEEN SWEDISH AND AMERICAN POST-POLIO INDIVIDUALS AND ASSESSMENT OF LOWER LIMB STRENGTH—A FOUR-YEAR COHORT STUDY

James C. Agre, MD, PhD,[1] Gunnar Grimby, MD, PhD,[2] Arthur A. Rodriquez, MD,[1] Gisli Einarsson, MD, PhD,[2,3] Eileen R. Swiggum, COTA[1] and Todd M. Franke, PhD[1,4]

*From the [1]Department of Rehabilitation Medicine, University of Wisconsin-Madison Medical School, Madison, Wisconsin; [2]Department of Rehabilitation Medicine, Göteborg University, Göteborg, Sweden; [3]Department of Rehabilitation Medicine, Reykjavik University Hospital, Reykjavik, Iceland (present address); and [4]Graduate School of Education/Social Research Methodology, University of California, Los Angeles, California, USA*

**ABSTRACT. A cohort study with initial and 4-year follow-up evaluations was performed in 78 post-polio volunteers aged 34–65 years at the time of enrolment in the study, which was made to compare post-polio individuals living in Sweden and the United States, to determine whether lower limb musculature becomes weaker over time, and to determine whether individuals with complaints of post-polio syndrome, new weakness, fatigue, walking or stair climbing difficulty were weaker or lost more strength over a 4-year interval than those individuals without such complaints. Dynametrically-measured knee extensor and flexor strength and questionnaire data were obtained initially and 4 years later. The two cohorts were fairly similar, though they differed in weight gain. The Americans gained significantly ($p < 0.05$) more weight than the Swedish subjects. Both groups lost significant ($p < 0.05$) knee extensor strength (approximately 8%), but the loss was not significantly ($p > 0.05$) different between the groups. Knee flexor strength did not change significantly ($p > 0.05$) over time. Subjects acknowledging new strength loss were not significantly ($p > 0.05$) weaker than those denying strength loss; however, they lost significantly ($p < 0.05$) more isometric knee extensor strength than the other individuals. Subjects acknowledging new fatigue, walking or stair climbing difficulty were significantly ($p < 0.05$) weaker in both muscle groups than those without such complaints. Subjects acknowledging post-polio syndrome were significantly ($p < 0.05$) weaker than those denying this symptom, but the amount of loss of strength over time was not significantly ($p > 0.05$) different. We conclude that the two cohorts were quite similar. Knee extensor strength decreased during the study interval. Individuals acknowledging post-polio syndrome had weaker knee extensor musculature. Subjects with new fatigue, walking difficulty, or stair climbing difficulty were weaker in both the knee extensors and the knee flexors than the other subjects. Subjects reporting new muscle weakness also had a greater decline in isometric knee extensor strength during the study interval than those without such complaint.**

*Key words:* neuromuscular diseases, poliomyelitis, post-polio syndrome, muscle strength, symptoms.

## INTRODUCTION

There are several reports in the literature that polio survivors complain of a number of new musculoskeletal and neuromuscular symptoms (1, 10, 12, 13, 17–19, 22). Whether the survivors were seen at a post-polio clinic (1, 18), or had responded to a national survey (17, 22), their most frequent new health complaints of polio survivors were fatigue, weakness, muscle pain and joint pain, while the most frequent new activities of daily living (ADL) complaints were difficulty with walking and stair climbing. These complaints, especially those of an ambulatory nature, may well be related to progressive decline in neuromuscular function in lower limb musculature of these individuals.

Although reports of progressive loss of strength long after the acute poliomyelitis illness have been appearing in the literature for over a century (11, 27), there is no objective substantiation of this view. In 1986, Dalakas et al. (13) reported a follow-up study of 27 post-polio individuals followed up for an average of 8.2 years. An average rate of decline in strength of 1% per year was reported; however, this decline was based not on quantitative testing, but on manual muscle testing, which is known to be very imprecise (7). There are three recent studies in the literature that

have used quantitative measures to assess muscle strength in polio survivors, but all were limited in the number of subjects followed or the duration of the follow-up period, or both. Munsat et al. (24) followed the strength of 6 post-polio patients for between 400 and 2,100 days, but no significant change in strength was found. Munin et al. (23) followed 7 post-polio patients for 3 years, but found no change in strength. Agre & Rodriquez found no significant change in strength in 44 post-polio subjects over a period of one year (3). Thus, to date, there is no objective evidence in the literature to document progressive loss of strength in post-polio patients, although this is a widely held belief and several plausible pathophysiological mechanisms have been suggested as the etiological cause of weakening (20).

Although the complaints by polio survivors appear to be similar in the several studies reported in the literature (1, 17, 18, 22) there have to our knowledge been no direct comparisons of post-polio survivors living in different societies. The purposes of this study were: 1) to compare poliomyelitis histories and present the status and symptoms of post-polio individuals living in two different countries, the USA and Sweden; 2) to determine whether these individuals would lose significant strength in the knee extensor (quadriceps) or knee flexor (hamstring) musculature during a 4-year period of time; and 3) to determine if subjects with complaints consistent with post-polio syndrome (using the definition of Halstead & Rossi [18]) or of new fatigue, weakness, walking difficulty, or stair climbing difficulty were weaker than the other post-polio individuals or lost strength at a more rapid rate in the lower limb musculature.

## MATERIALS AND METHODS

### *Subjects*

A total of 78 subjects were assessed initially and then after a 4-year interval. 41 subjects lived in the vicinity of Göteborg (Gothenburg), Sweden and 37 lived in the environs of Madison, Wisconsin, USA. The Swedish subjects were recruited on two separate occasions. On the first occasion (in 1986), 21 of the subjects were traced back to 1950, through the hospital register in Göteborg of former polio patients. The only additional inclusion requirement was to be between the ages of 44 and 65 years at the time of the enrolment (14, 16). The second group of 20 subjects were recruited through advertisements in the daily press and through the post-polio patient organization in 1988, with the only criterion to be at least a partial ambulator and to be at or below 45 years of age at the time of enrollment (16). The American subjects were recruited during a one-year period between the summer of 1987 and 1988 to participate in a longitudinal study of neuromuscular function in polio survivors through newspaper advertisements, solicitation from the Wisconsin Easter Seal Society, and by word of mouth (2).

All subjects were between 34 and 65 years of age when initially evaluated. All had a history consistent with poliomyelitis and had their acute poliomyelitis illness at least 30 years prior to the onset of the study. All subjects had enjoyed partial or fairly complete recovery from their acute poliomyelitis illness and a period of neurologic stability. All subjects were essentially healthy at the time of the initial evaluation and denied significant medical problems that would either contra-indicate maximum effort testing or might be expected to cause neuromuscular deterioration, such as heart disease, cancer, and endocrinological diseases.

In order to participate in the study, a subject had to have a history and physical examination compatible with poliomyelitis and have greater than antigravity muscle strength in at least one knee extensor muscle group. Strength was evaluated in only one lower limb affected by polio in all subjects in this study. If the subject acknowledged only one lower limb to have been affected initially by polio, that side was tested. If both lower limbs were acknowledged to have been affected initially by polio, the stronger limb was evaluated. All subjects who fulfilled the above study criteria were included in the study. Although this study assessed lower limb muscle strength, ambulatory difficulty was not a specific criterion for subject selection.

At the beginning of the study, all subjects completed a detailed questionnaire concerning their acute poliomyelitis illness, recovery thereafter, and status and symptoms at that time. The questionnaires used in Göteborg and Madison were essentially identical, except, of course, for the language difference. At the time of the follow-up evaluation, 4 years later, all subjects completed a questionnaire recording their current symptoms and status. In order to classify whether a subject had post-polio syndrome, the criteria of Halstead & Rossi (18) were utilized. Briefly, these included 1) a history of paralytic poliomyelitis; 2) partial to fairly complete recovery; 3) a period of neurologic stability; 4) the onset of two or more of the following health problems since achieving a period of stability: unaccustomed fatigue, muscle and/or joint pain, new weakness in muscles previously affected and/or unaffected, functional loss, cold intolerance, new atrophy; and 5) no other medical diagnosis to explain these health problems.

The research project was approved by each university's Ethics Committee, and informed consent was given by all subjects before participation.

### *Strength testing*

The knee extensors were tested isokinetically and isometrically, while the knee flexors were tested isokinetically using myodynamometers (Lido Active Dynamometer in the US cohort, a modified Cybex II dynamometer in the first group of 21 Swedish subjects, and a KinCom dynamometer for the second group of 20 Swedish subjects). No difference was found in peak torque of the two dynamometers used in the Swedish Laboratory when 23 healthy subjects aged 21–84 years were assessed (15). The Lido and Cybex II dynamometers have been previously reported to be reliable in post-polio subjects (2, 14) and the KinCom was found to have methodologic errors of 6–10% at various angular velocities in 30 post-polio subjects assessed 3 months apart. The angular velocity for the isokinetic testing was performed

Table I. *Descriptive data comparing subjects by nationality (expressed as mean ± SD or a percentage)*

| | American subjects ($n = 37$) | Swedish subjects ($n = 41$) | $p$ |
|---|---|---|---|
| Present age (years) | 48 ± 6.2 | 52 ± 8.7 | 0.015 |
| Age (at onset of acute polio, years) | 6.9 ± 5.8 | 9.0 ± 8.2 | ns |
| Time (from acute polio to first evaluation, years) | 37 ± 4.5 | 39 ± 6.8 | ns |
| Height (cm) | 169 ± 10.9 | 168 ± 8.5 | ns |
| Weight (at first evaluation, kg) | 70.9 ± 15.9 ($n = 36$) | 66.5 ± 11.2 ($n = 39$) | ns |
| Weight (at second evaluation, kg)[a] | 74.8 ± 17.7 ($n = 36$) | 67.2 ± 11.2 ($n = 39$) | 0.028 |
| Gender | | | |
| Percentage male | 38% | 36% | ns |
| Percentage female | 62% | 64% | ns |
| Percentage with post-polio syndrome (PPS)[b] (at first evaluation) | 68% | 60% | ns |
| Percentage with PPS (at second evaluation) | 76% | 73% | ns |
| Time (from acute polio to onset of PPS symptoms, years) | 32 ± 7.8 ($n = 28$) | 33 ± 10.0 ($n = 30$) | ns |

[a] Significant ($p < 0.05$) overall effect for weight, regardless of group. Significant interaction ($p < 0.05$) between groups and time. The American cohort gained significantly ($p < 0.05$) more weight than the Swedish cohort over the 4-year interval.
[b] As defined by Halstead & Rossi (18).

at 60°/second. Each Swedish subject performed 3 maximum effort knee extension and flexion movements, while each American subject performed 6 maximum effort knee extension and flexion movements. The peak torque for both knee extension and flexion for each subject was recorded for subsequent analysis. The isometric knee extension testing was performed with the knee positioned 60° from straight. All subjects performed three maximum effort isometric knee extensions with one minute rest breaks between trials. The methodology is detailed elsewhere (2, 14–16). Muscle strength testing was performed in the respective research laboratories initially and 4 years later. (The variation in time in repeat testing for all subjects was never more than 1–2 months from the 4-year anniversary.)

### *Statistical analyses*

In order to assess significant differences between the two cohorts regarding percentage of subjects acknowledging any particular variable from the questionnaire, the Pearson $\chi^2$-test was performed. In order to assess significant differences between mean values of the two cohorts, independent sample $t$-tests were performed and between groups regarding strength or significant change in strength over time, MANOVA was performed. When the total cohort was divided into more than two groups and the main effect from the MANOVA analysis revealed a significant difference among groups, Fisher's least significant difference (LSD) post hoc test was used to determine between which groups significant differences existed. For all analyses, statistical significance was defined as $p < 0.05$.

## RESULTS

### *Questionnaire data*

Descriptive data comparing the subjects by nationality are given in Table I. No significant differences were found between the two cohorts except for present age and weight at the time of the 4-year follow-up. The Swedish subjects were 4 years older than the American subjects, on the average. The American subjects gained significantly more weight than the Swedish subjects over the 4-year time span of this study (an average increase of 4.0 versus 0.7 kg, respectively, $p < 0.05$). No significant ($p > 0.05$) differences were found when the data were analysed using gender as the grouping factor (excluding, of course, the gender variable).

No significant ($p > 0.05$) differences were found between the two groups regarding initial poliomyelitis involvement of arms (50% of subjects), trunk (58% of subjects), or respiratory function (20% of subjects); however, more Swedish subjects acknowledged acute poliomyelitis involvement of lower limb musculature (93% vs. 73% of subjects, $p < 0.05$). No significant ($p > 0.05$) differences were found when the data were analysed using gender as the grouping factor.

Acknowledgement of post-polio symptoms (as defined by Halstead & Rossi [18]) and locomotor dysfunction by the subjects at the time of the 4-year follow-up evaluation is shown in Table II. No significant ($p > 0.05$) differences were found between the two cohorts for any of the post-polio syndrome symptoms or locomotor dysfunction and no

Table II. *Comparison of subjects acknowledging the various post-polio syndrome (PPS) symptoms[a] or locomotor dysfunction at the time of the second evaluation (expressed as percentage of individuals)*

| | American subjects ($n = 37$) (%) | Swedish subjects ($n = 41$) (%) | $p$ |
|---|---|---|---|
| *PPS symptoms* | | | |
| Fatigue | 57 | 71 | ns |
| Weakness | 43 | 55 | ns |
| Atrophy | 14 | 12 | ns |
| Muscle pain | 51 | 36 | ns |
| Joint pain | 50 | 57 | ns |
| Cold intolerance | 16 | 26 | ns |
| *Locomotor dysfunction* | | | |
| Walking difficulty | 38 | 52 | ns |
| Stair climbing difficulty | 38 | 45 | ns |
| Wheelchair use | 8 | 14 | ns |
| Cane use | 17 | 36 | ns |
| Orthosis use | 28 | 26 | ns |

[a] As defined by Halstead & Rossi (18).

significant ($p > 0.05$) differences were found when the data were analysed using gender as the grouping factor, except for the complaint of cold intolerance. Surprisingly, more men (than women) complained of cold intolerance (34% vs. 14%, respectively, $p = 0.033$).

*Strength data*

The comparison of change in strength of the knee extensors and flexors between the two cohorts is found in Table III. Although the Swedish cohort can be seen to have lower strength values in the lower limb musculature, a direct statistical comparison of strength between the two cohorts was not made, as different dynamometers which were not directly compared were utilized in the two different research laboratories. For the total cohort, both measures of knee extensor strength revealed a significant ($p < 0.05$) loss over the 4-year interval (average loss of 9%, when measured isokinetically, and 7%, isometrically). No significant ($p > 0.05$) difference, however, was found between the two cohorts regarding the amount of loss of strength over the 4-year time-span. Knee flexor strength did not change significantly ($p > 0.05$) over the 4-year period. When the data were analysed using gender as the grouping factor, the men were, not surprisingly, stronger ($p < 0.05$, data not shown). The men were found to lose significantly more strength of the knee extensors than the women when measured isokinetically (12% vs. 7% loss, respectively, $p < 0.05$), but not when measured isometrically (7% vs. 5% loss, respectively, $p > 0.05$).

*Combination of questionnaire and strength data*

Table IV shows the strength results when the total cohort was divided into three groups according to their acknowledgement of post-polio syndrome (using the criteria of Halstead & Rossi [18]). Subjects were divided into: 1) those subjects acknowledging post-polio syndrome at the time of the initial assessment

Table III. *Change in strength between the American and Swedish subjects when comparing strength (mean ± SD, in Newton meters) at the time of the initial and second evaluations (performed 4 years later)*[a]

| | Total | American subjects | Swedish subjects |
|---|---|---|---|
| Knee extensors, isokinetic[b,c] | ($n = 78$) | ($n = 37$) | ($n = 41$) |
| First evaluation | 96 ± 59.5 | 108 ± 67.7 | 86 ± 49.6 |
| Second evaluation | 87 ± 53.6 | 97 ± 62.4 | 79 ± 43.4 |
| Knee extensors, isometric[b,c] | ($n = 77$) | ($n = 37$) | ($n = 40$) |
| First evaluation | 118 ± 67.8 | 136 ± 79.0 | 101 ± 50.8 |
| Second evaluation | 110 ± 67.6 | 131 ± 78.2 | 91 ± 49.7 |
| Knee flexors, isokinetic[c] | ($n = 73$) | ($n = 33$) | ($n = 40$) |
| First evaluation | 50 ± 29.4 | 60 ± 31.9 | 41 ± 24.5 |
| Second evaluation | 51 ± 30.3 | 60 ± 35.6 | 43 ± 22.7 |

[a] The two groups were not directly compared, as different dynamometers were used to assess them.
[b] There is a significant ($p < 0.05$) change in strength over time for the whole cohort.
[c] The change in strength from the first to the second evaluation when comparing the two groups is not significantly ($p > 0.05$) different.

Table IV. *Comparison of strength (mean ± SD, in Newton meters) and change in strength in subjects acknowledging postpolio syndrome symptoms at the time of both evaluations (PPS Both), acknowledging postpolio symptoms only at the time of the second evaluation (PPS 2 Only), and those not acknowledging postpolio syndrome symptoms at either evaluation (PPS Never)*

| | PPS Both | PPS 2 Only | PPS Never |
|---|---|---|---|
| Knee extensors, isokinetic[a,b,c] | ($n = 50$) | ($n = 7$) | ($n = 21$) |
| First evaluation | 84 ± 58.2 | 104 ± 73.4 | 122 ± 51.2 |
| Second evaluation | 75 ± 52.6 | 96 ± 66.1 | 114 ± 43.2 |
| Knee extensors, isometric[a,b,c] | ($n = 49$) | ($n = 7$) | ($n = 21$) |
| First evaluation | 105 ± 66.8 | 124 ± 86.0 | 146 ± 57.6 |
| Second evaluation | 96 ± 67.4 | 112 ± 82.3 | 143 ± 53.4 |
| Knee flexors, isokinetic[c] | ($n = 45$) | ($n = 7$) | ($n = 21$) |
| First evaluation | 45 ± 28.1 | 48 ± 28.6 | 60 ± 30.8 |
| Second evaluation | 46 ± 29.3 | 58 ± 35.0 | 59 ± 30.1 |

[a] The main effect shows a significant ($p < 0.05$) difference among groups. Fisher's LSD post hoc analyses show a significant ($p < 0.05$) difference between PPS Both and PPS Never.
[b] There is a significant ($p < 0.05$) change in strength over time for the whole cohort.
[c] The change in strength from the first to the second evaluation when comparing the three groups is not significantly ($p > 0.05$) different.

and the time of the follow-up evaluation (PPS Both), 2) those acknowledging post-polio syndrome at the follow-up evaluation only (PPS 2 Only), and 3) those not acknowledging post-polio syndrome at the time of either evaluation (PPS Never). Of note, no subjects had symptoms compatible with post-polio syndrome at the first evaluation who did not have these symptoms at the time of the second evaluation. The main effect of the MANOVA showed a significant ($p < 0.05$) difference among groups for knee extensor strength measured both isokinetically and isometrically. Fisher's LSD post hoc test showed that the group acknowledging post-polio syndrome symptoms on both occasions (PPS Both) were significantly ($p < 0.05$) weaker than the group that never acknowledged post-polio syndrome (PPS Never) for both of these variables. The main effect of the MANOVA showed no significant difference among the groups regarding knee flexor strength. The rate of loss in strength over time was not significantly ($p > 0.05$) different among the three groups for any of the three strength variables.

Table V shows the strength results when the total cohort was divided into those who acknowledged vs. did not acknowledge new weakness. The main effect of the MANOVA revealed no significant ($p > 0.05$) difference between the two groups for any of the three strength variables. The rate of loss in knee extensor strength, however, was significantly greater in the group complaining of new weakness when measured isometrically (12% vs. 2% loss, $p < 0.05$), but not when measured isokinetically (13% vs. 7% loss, $p > 0.05$).

Table VI shows the strength results when the total cohort was divided into groups who acknowledged vs. did not acknowledge new fatigue. For all three strength variables, the main effect of the MANOVA showed that the group acknowledging new fatigue

Table V. *Comparison of strength (mean ± SD in Newton meters) and change in strength in subjects acknowledging and not acknowledging new muscle weakness*[a]

| | New weakness | No new weakness |
|---|---|---|
| Knee extensors, isokinetic[b] | ($n = 38$) | ($n = 40$) |
| First evaluation | 86 ± 58.0 | 106 ± 59.9 |
| Second evaluation | 75 ± 48.6 | 99 ± 55.9 |
| Knee extensors, isometric[b,c] | ($n = 37$) | ($n = 40$) |
| First evaluation | 106 ± 63.7 | 129 ± 70.5 |
| Second evaluation | 93 ± 61.5 | 126 ± 69.9 |
| Knee flexors, isokinetic | ($n = 35$) | ($n = 38$) |
| First evaluation | 45 ± 28.1 | 54 ± 30.1 |
| Second evaluation | 47 ± 28.6 | 55 ± 31.7 |

[a] The main effect does not show a significant ($p > 0.05$) difference between groups for any of the three strength variables.
[b] There is a significant ($p < 0.05$) change in strength over time for the whole cohort.
[c] The change in strength from the first to the second evaluation when comparing the two groups is significantly ($p < 0.05$) different.

Table VI. *Comparison of strength (mean ± SD, in Newton meters) and change in strength in subjects acknowledging and not acknowledging new fatigue*

| | New fatigue | No new fatigue |
|---|---|---|
| Knee extensors, isokinetic[a,b,c] | ($n = 50$) | ($n = 28$) |
| First evaluation | 85 ± 53.1 | 116 ± 66.0 |
| Second evaluation | 78 ± 48.5 | 105 ± 58.7 |
| Knee extensors, isometric[a,b,c] | ($n = 50$) | ($n = 27$) |
| First evaluation | 106 ± 59.9 | 140 ± 76.7 |
| Second evaluation | 99 ± 61.3 | 132 ± 74.3 |
| Knee flexors, isokinetic[a,c] | ($n = 48$) | ($n = 25$) |
| First evaluation | 42 ± 25.4 | 64 ± 31.3 |
| Second evaluation | 45 ± 27.6 | 63 ± 32.1 |

[a] The main effect shows a significant ($p < 0.05$) difference between groups.
[b] There is a significant ($p < 0.05$) change in strength over time for the whole cohort.
[c] The change in strength from the first to the second evaluation when comparing the two groups is not significantly ($p > 0.05$) different.

was significantly ($p < 0.05$) weaker than the group denying new fatigue. The loss in strength over time, however, did not differ significantly ($p > 0.05$) between the two groups for any of the three strength variables. Similar findings were made when the cohort was divided into those who acknowledged new walking difficulty ($n = 35$) and those who did not acknowledge new walking difficulty ($n = 43$) or those who acknowledged new stair climbing difficulty ($n = 32$) or did not acknowledge new stair climbing difficulty ($n = 46$) except that the group acknowledging new stair climbing difficulty lost significantly more knee extensor strength when measured isometrically over the 4-year time span than the group denying new stair climbing difficulty (14% vs. 3% loss, $p < 0.05$). However, no significant difference was found between these two groups regarding change in knee extensor strength when the measurement was made isokinetically (12% vs. 8% loss, $p > 0.05$).

The total cohort was also divided into those who did vs. did not acknowledge one or more new medical problems in the intervening 4 years of the study that might be expected to affect lower limb muscle strength (such as history of lower limb fracture, strain, or sprain, or acknowledgment of lower limb joint pain). The main effect of the MANOVA showed no significant ($p > 0.05$) difference between the two groups for any of the three strength variables and the loss of strength did not differ significantly ($p > 0.05$) between the two groups. Similar findings were made when the total cohort was divided into those who did vs. did not acknowledge new medical problems of any sort in the intervening 4 years of the study.

## DISCUSSION

### *Comparison of Swedish and American cohorts*

This study reports the experiences of Swedish and American post-polio subjects and changes that have occurred over a four-year interval of time. This study has allowed for a cross-country comparison of post-polio subjects and also for analysis of a larger group of post-polio subjects. One weakness of this study concerned subject selection. Unfortunately, the subjects could not be randomly selected by appropriate epidemiologic procedure, as this was not possible in either location. Thus, this paper reports the results of those subjects whom we were able to recruit initially and reassess 4 years later.

Of the 21 separate variables compared, the two cohorts differed in only three. Taken as a whole, the two cohorts appear to be much more similar than dissimilar. The three variables where the two groups differed were: present age, weight gain, and acknowledgment of initial poliomyelitis involvement of the lower limbs. The Swedish cohort was older than the American, by an average of 4 years. Although the two groups were of similar body weight at the time of the initial evaluation, the American cohort gained more weight during the 4-year interval of the study. On average, the American subjects gained 1 kg per year, compared with the average gain of approximately 175 g/year in the Swedish subjects. Although body composition was not measured in these individuals, we believe that the increase in weight was due to deposition of adipose tissue and not to an increase in lean body (muscle) mass. The lack of increase in lean body mass appears to be substantiated by the significant loss in knee extensor strength, which would be compatible with atrophy of the muscle rather than hypertrophy. Also, the proportion of Swedish subjects acknowledging initial involvement of the lower limbs is greater than the American cohort. This is almost likely due to the selection process of the subjects rather than to some other factor. The American subjects were recruited to participate in a longitudinal study of muscle strength in polio survivors. Subjects with and without complaints of declining

function were equally actively recruited. The Swedish subjects included subjects who were recruited to participate in two separate post-polio research projects. In the recruitment of the second Swedish group, mainly individuals with partial ambulatory function were enrolled. This factor may have had an influence on the difference between the American and the Swedish cohorts. It should also be pointed out, as described previously (21), that more individuals had initial poliomyelitis involvement in the lower limbs than in the upper limbs.

We believe that the weight gain found in our subjects, especially the American subjects, is due cause for concern. The reason for the difference in weight gain is not known, but may well be related to cultural, dietary, and/or activity level differences between the American and the Swedish cohorts. The typical American lifestyle is rather sedentary and the diet tends to contain an excessive amount of fat. Both of these factors can lead to the deposition of adipose tissue. Regardless of the reasons, weight gain may have a very significant adverse effect on the individual's ability to function.

### *Evaluation of strength*

We acknowledge that another weakness of this study is the use of different dynamometers in the two separate research laboratories. However, as it was not our intention to directly compare the strength of the Swedish and American subjects, but rather to compare the rate of change in strength in our two post-polio groups, we do not regard this as a significant weakness. In order to determine rate of change in strength over time, reliable dynamometry is needed in both laboratories, as was the case in the present study (2, 14, 15).

In this study, we assessed the strength of the knee extensor and flexor muscles in polio-affected muscles in post-polio subjects with greater than antigravity strength. When both lower limbs were affected by polio, the stronger limb was assessed in this study. The weaker limb was not assessed and, in our subjects, the weaker limb varied from total or near-total paralysis to near-normal function. Thus, the load borne by the stronger limb in the performance of daily activities in these subjects varied considerably. Moreover, it should be pointed out that, although we only assessed muscle strength in subjects with greater than antigravity strength, the measured strength in our subjects was quite disparate as evidenced by the large standard deviations of the strength measures. This is not an unexpected finding in post-polio subjects, who are known to be rather heterogeneous.

The post-polio subjects in this study had significantly less strength than non-post-polio, control subjects. Compared with a Swedish cohort of control subjects of similar age and gender, the Swedish post-polio subjects had an average strength of the knee extensors, measured isokinetically, of approximately 50% of normal strength (16). Compared with an American cohort of control subjects of similar age and gender, the American post-polio subjects had an average strength of the knee extensors, measured isokinetically, of approximately 65% of normal strength (2).

Although reports of progressive loss of strength long after the acute poliomyelitis illness have been appearing in the literature for well over a century (11, 27), prior to this study there has been no objective substantiation of this conviction. This report, as well as the results from the Swedish cohort reported herein and recently published elsewhere (15, 16), are to our knowledge the first reports in the refereed literature, to objectively demonstrate loss in strength over time in the post-polio individual's musculature. Utilizing quantitative methodology to assess strength, an average decline of approximately 2% per year was found in the strength of the knee extensor musculature in these 78 post-polio subjects. Although assessment of these subjects' data cannot demonstrate whether this loss in strength is greater than could have been expected from the ageing process alone, as a similar number of control (non-polio) subjects were not also studied, comparison of our data to that reported in the literature from cross-sectional studies (5, 8, 25, 31) demonstrates that our subjects appear to lose strength at a rate approximately twice that found in unimpaired subjects. It is quite possible that the loss in strength in the knee extensor musculature in these subjects is due to a combination of the loss associated with the ageing process as well as to etiological factors related to the post-polio condition. Further research will be needed to clarify this.

Although the knee extensors were found to lose strength over the 4-year interval when measured either isokinetically or isometrically, the knee flexors were not found to lose over this interval. At the present

time, we have no explanation for this particular finding. It should also be pointed out that although the Swedish cohort had lower initial strength values and were older than the American cohort, the rate of loss of strength over time did not differ when comparing the two groups for either the knee extensor or flexor musculature.

*Comparison of strength and change in strength with post-polio syndrome symptoms*

In this study we wished to determine whether subjects with post-polio syndrome or with complaints of new fatigue, weakness, walking difficulty, or stair climbing difficulty were weaker than the other subjects initially, or lost more strength over the 4-year interval of the study than the other subjects. We also wished to learn whether the presence of medical problems during the 4-year interval of the study affected the rate of change in strength in these subjects.

*Post-polio syndrome.* The data show that the group acknowledging post-polio syndrome at the time of both evaluations were significantly weaker in the knee extensor muscles than the group that never acknowledged having post-polio syndrome. The group of subjects who developed post-polio syndrome during the intervening 4 years were found to have strength intermediate to the other two groups. No differences were found among the three groups regarding rate of loss of knee extensor strength. As weaker subjects might be expected to experience more problems related to overuse phenomena, a common problem found in post-polio patients (1, 26), it does not seem to be surprising that the group acknowledging post-polio syndrome at the time of both evaluations in this study was the weakest group, while the group acknowledging post-polio syndrome at the time of the second evaluation had an average strength value intermediate to the other two groups.

*New fatigue.* When comparing the mean strength data of those subjects acknowledging new fatigue vs. those not acknowledging it, it is evident that the former were significantly weaker in the knee extensors and the flexors than the other subjects. No difference was found between the two groups, however, regarding the rate of loss of strength over the 4-year interval of this study. If one assumes that the weakness found in the lower limb muscles evaluated in this study reflects a more generalized weakness in these individuals, it is understandable why these subjects would experience more fatigue. In order for weaker individuals to perform their daily activities, they must utilize their muscles at levels closer to maximum strength. Moreover, it is well known that the higher the relative intensity of the activity, the more rapidly will the individual suffer fatigue (30). It has also been shown that individuals with post-polio syndrome have greater difficulty in recovering muscular strength after exhausting exercise, which appears to be related to excessive local muscle fatigue (2, 28, 29). Our findings from this study, however, do not exclude other possible causes for new fatigue in post-polio individuals. A recent study by Bruno et al. (9) postulated that fatigue was related to damage to the brain activating system, at least in some post-polio individuals.

*New weakness.* When our total cohort was divided into two groups by acknowledgement of new weakness, it was found that the group complaining of new weakness had lower mean values for the strength of their knee extensor and flexor musculature, but this difference was not statistically significant. However, when comparing the mean values for knee extensor and flexor strength of those subjects complaining of new weakness vs. that of the individuals complaining of new fatigue or of post-polio syndrome at the time of both evaluations (PPS Both), the values were remarkably similar. This finding may reflect a 'threshold phenomenon' (16). That is to say, when an individual loses strength down to some certain critical value, the relative amount of effort that the individual must exert to complete activities of daily living will become sufficiently close to maximum effort that he/she will have little remaining reserve and will become more aware of their difficulties. Should these individuals continue to lose strength, they might ultimately lose the ability to perform some activities that they were previously capable of.

It should also be pointed out that the group complaining of new weakness may weaken more quickly than those subjects not complaining of new weakness. Although the strength of the knee extensor musculature was becoming weaker in the total cohort, when knee extensor strength was assessed isometrically, the rate of loss was significantly greater in the group acknowledging new weakness (12% loss over the 4-year interval vs. a 2% loss). The reason for this difference is not known at the present time, but warrants further research.

It was also found that the men lost significantly

more isokinetic knee extensor strength over the 4-year interval than did the women (12% vs. 7% loss). We are unable to identify a specific reason for this finding from our data set. Our data analyses revealed no differences between the men and women in this study regarding their descriptive data, body areas initially affected by polio, new symptomatology (except for the complaint of cold intolerance), or acknowledgement of locomotor dysfunction.

*New walking or stair climbing difficulty*. When comparing the average data of those subjects acknowledging either new walking difficulty or new stair climbing difficulty, vs. those not acknowledging these problems, it is seen that subjects with these complaints are significantly weaker than the other subjects. The average strength for the knee extensors and flexors for the subjects with new walking difficulty is approximately 35% less than that of the other subjects, while for subjects with new stair climbing difficulty, the average strength of the subjects with the complaints is approximately 40–45% less than that of the other subjects. It should not be surprising to learn that those subjects with the new stair climbing difficulty are the subjects with the weakest knee extensor and flexor muscles, as these muscle groups are important in the performance of stair climbing (6). Due to this weakness, these subjects must activate their musculature to near-maximum levels when climbing stairs, so that any reduction in strength over time will result in greater difficulty in climbing stairs. Our data also show that subjects acknowledging new stair climbing difficulty do lose knee extensor strength, as determined isometrically, at a greater rate than those subjects without this complaint. The reason for this finding is not known, but these subjects may very well have reached strength levels where stair climbing became so difficult that they deliberately avoided doing so. This limitation in activity would then lead to further weakening due to muscle disuse (4).

*New medical problems*. We attempted to determine whether the noted loss of strength was related to medical problems that the individuals experienced over the 4-year interval of this study. It does not appear that intervening medical problems were related to the loss of strength in these subjects, as there was no difference in initial strength or change in strength over time when the total cohort was divided into groups with vs. without the acknowledgement of new medical problems.

## RÉSUMÉ

The American and Swedish post-polio cohorts were found to be quite similar; no significant differences were found between the two cohorts regarding 18 of the 21 variables examined. Of note, weight was found to increase in these subjects over the 4-year time span. In the same period, strength of the knee extensor musculature declined by approximately 8%. Individuals acknowledging post-polio syndrome at the time of both evaluations were the weakest individuals, while those denying post-polio syndrome at the time of both evaluations were the strongest. Although the subjects of this study were found to lose significant knee extensor strength during the course of this study, those subjects acknowledging progressive weakness were found to lose knee extensor strength, when measured isometrically, at a greater rate than those not acknowledging new weakness. Subjects with new fatigue, walking difficulty, or stair climbing difficulty were found to be weaker in both the knee extensors and the knee flexors than those subjects not acknowledging these symptoms.

We believe that three significant implications arise from this study. First of all, as our two post-polio groups were found to be quite similar, it is conceivable that this might also be the case when comparing other post-polio groups. This finding may have therapeutic implications because, should a therapeutic endeavour be found to be beneficial for some post-polio individuals, other post-polio individuals might also be beneficially affected. Secondly, post-polio individuals tend to gain weight as they age and this may have an adverse affect on their functional abilities. And, thirdly, over the time course of this study, we have objectively demonstrated a loss in strength in our post-polio individuals with an increase in the proportion of subjects with symptoms compatible with the diagnosis of post-polio syndrome. One would expect that the proportion of post-polio individuals experiencing difficulties in the future will continue to increase. Thus, the importance of rehabilitation interventions needed to assist these individuals in maximizing their functional abilities deserves emphasis.

## ACKNOWLEDGEMENTS

This research was supported by the United States Depart-

ment of Education (NIDRR grants H133G10210 and H133G40040), The Easter Seal Research Foundation (grant no. N-8629), The University of Wisconsin Graduate School, the Swedish Medical Research Council (Project 3888), King Gustav V 80 Years Foundation and the Swedish Association for Traffic and Polio Victims.

## REFERENCES

1. Agre, J. C., Rodriquez, A. A. & Sperling, K. B.: Symptoms and clinical impressions of patients seen in a postpolio clinic. Arch Phys Med Rehabil *70:* 367–370, 1989.
2. Agre, J. C. & Rodriquez, A. A.: Neuromuscular function: comparison of symptomatic and asymptomatic polio subjects to control subjects. Arch Phys Med Rehabil *71:* 545–551, 1990.
3. Agre, J. C. & Rodriquez, A. A.: Neuromuscular function in polio survivors at one-year follow-up. Arch Phys Med Rehabil *72:* 7–10, 1991.
4. Agre, J. C., Rodriquez, A. A. & Tafel, J. A.: Late effects of polio: critical review of the literature on neuromuscular function. Arch Phys Med Rehabil *72:* 923–931, 1991.
5. Asmussen, E.: Aging and exercise. In: Environmental physiology: aging, heat, and altitude (eds. S. M. Horvath & M. K. Yousef), pp. 419–428. Elsevier, Amsterdam, 1980.
6. Basmajian, J. V.: Muscular tone, fatigue, and neural influences. In: Muscles alive, 4th edn, pp. 79–114. Williams and Wilkins, Baltimore, 1978.
7. Beasley, W. C.: Quantitative muscle testing: principles and applications for research and clinical services. Arch Phys Med Rehabil *42:* 398–425, 1961.
8. Borges, O.: Isometric and isokinetic knee extension and flexion torque in men and women aged 20–70. Scand J Rehabil Med *21:* 45–53, 1989.
9. Bruno, R. L., Cohen, J. M., Galski, T. & Frick, N. M.: The neuroanatomy of post-polio fatigue. Arch Phys Med Rehabil *75:* 498–504, 1994.
10. Codd, M. B., Mulder, D. W., Kurland, L. T., Beard, C. M., O'Fallon, W. M.: Poliomyelitis in Rochester, Minnesota, 1935–1955: epidemiology and long-term sequelae: a preliminary report. In: Late effects of poliomyelitis (eds. L. S. Halstead & D. O. Wiechers), pp. 121–134. Symposia Foundation, Miami, 1985.
11. Cornil Lepine: Sur un cas de paralysie generale spinale anterieure subaigue, suivi d'autopsie. Gaz Med Fr (Paris) *4:* 127–129, 1875.
12. Cosgrove, J. L., Alexander, M. A., Kitts, E. L., Swan, B. E., Klein, M. J. & Bauer, R. E.: Late effects of poliomyelitis. Arch Phys Med Rehabil *68:* 4–7, 1987.
13. Dalakas, M. B., Elder, G., Hallat, M., Ravits, J., Baker, M., Papadopoulos, N., Albrecht, P. & Sever, J.: A long-term follow-up study of patients with post-poliomyelitis neuromuscular symptoms. N Engl J Med *314:* 959–963, 1986.
14. Grimby, G., Einarsson, G., Hedberg, M. & Aniansson, A.: Muscle adaptive changes in post-polio subjects. Scand J Rehabil Med *21:* 19–26, 1989.
15. Grimby, G., Hedberg, M. & Henning, G-B.: Changes in muscle morphology, strength and enzymes in a four–five-year follow-up of subjects with poliomyelitis sequelae. Scand J Rehabil Med *26:* 121–130, 1994.
16. Grimby, G. & Thorén-Jönsson, A.-L.: Disability in poliomyelitis sequelae. Phys Ther *74:* 415–424, 1994.
17. Halstead, L. S. & Rossi, C. D.: New problems in old polio patients: results of a survey of 539 polio survivors. Orthopedics *8:* 845–850, 1985.
18. Halstead, L.S. & Rossi, C.D.: Postpolio syndrome: clinical experience with 132 consecutive outpatients. In: Research and clinical aspects of the late effects of poliomyelitis (eds. L. S. Halstead & D. O. Wiechers), pp. 13–26. March of Dimes Birth Defects Foundation, White Plains, NY, 1987.
19. Halstead, L. S. & Wiechers, D. O. (eds.): Research and clinical aspects of the late effects of poliomyelitis. pp. 1–363. March of Dimes Birth Defects Foundation, White Plains, NY, 1987.
20. Jubelt, B. & Cashman, N. R.: Neurological manifestations of the post-polio syndrome. CRC Crit Rev Clin Neurobiol *3:* 199–220, 1987.
21. Kincaid, J. L.: Myelitis and myelopathy. In: Clinical neurology (ed. R. L. Joynt), chapter 48, p. 14. Harper & Row, Hagerstown, MD, 1989.
22. Lønnberg, F.: Late onset polio sequelae in Denmark, presentation and results of a nation-wide survey of 3,607 polio survivors. Scand J Rehabil Med, Suppl. 28: 7–15, 1993.
23. Munin, M. C., Jaweed, M. M., Staas, W. E., Satinsky, A. R., Gutierez, F. & Herbison, G. J.: Poliomyelitis muscle weakness: a prospective study of quadriceps strength. Arch Phys Med Rehabil *72:* 729–733, 1991.
24. Munsat, T. L., Andres, P. & Thibideau, L.: Preliminary observations on long-term muscle force changes in the post-polio syndrome. In: Research and clinical aspects of the late effects of poliomyelitis (eds. L. S. Halstead & D. O. Wiechers), pp. 329–334. March of Dimes Birth Defects Foundation, White Plains, NY, 1987.
25. Murray, M. P., Gardner, G. M., Mollinger, L. A. & Sepic, S.B.: Strength of isometric and isokinetic contractions. Knee Muscles of men aged 20 to 86. Phys Ther *60:* 412–419, 1980.
26. Perry, J., Barnes, G. & Grønley, J.K.: The postpolio syndrome: an overuse phenomenon. Clin Orthop *233:* 145–162, 1988.
27. Raymond, M. (with contribution by Charcot, J. M.): Paralysie essentiele de l'enfance: atrophie musculaire consecutive. Gaz Med Fr (Paris) *4:* 225, 1875.
28. Rodriquez, A. A. & Agre, J. C.: Electrophysiologic study of the quadriceps muscles during fatiguing exercise and recovery: a comparison of symptomatic postpolios to asymptomatic postpolios and controls. Arch Phys Med Rehabil *72:* 993–997, 1991.
29. Rodriquez, A. A., Agre, J. C., Black, P. O. & Franke, T. M.: Motor unit firing rates in postpolio and control subjects during submaximal contraction. Am J Phys Med Rehabil *70:* 191–194, 1991.
30. Rohmert, W.: Ermittlung von Erholungspausen für statische Arbeit des Menschen. Int Z Angew Physiol *18:* 123–164, 1960.
31. Young, A., Stokes, M. & Crowe, M.: Size and strength of the quadriceps muscles of old and young women. Eur J Clin Invest *14:* 282–287, 1984.

*Address for offprints:*

Prof. Gunnar Grimby
Dept. of Rehabilitation Medicine
Sahlgrenska Univ. Hospital
S-413 45 Göteborg
Sweden