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OVERUSE SYMPTOMS: A MODEL BASED ON POLIO SURVIVORS

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3 **The Relationship Between Lower Extremity Strength and Shoulder Overuse Symptoms:**

4 **A Model Based on Polio Survivors**

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11  
12 Supported by grant DAMD17-95-1-5079 from the U.S. Department of the Army.

13  
14  
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24 **ABSTRACT**

25 **Objective:** To determine the relationship between lower extremity weakness and shoulder  
26 overuse symptoms among polio survivors. We predicted that individuals with moderate  
27 weakness in their leg extensor muscles use their arms to help compensate for this weakness and  
28 would be at high risk for developing symptoms of shoulder overuse.

29 **Design:** A cohort study of polio survivors recruited from the Einstein-Moss Post-Polio  
30 Management Program, the community and the surrounding tri-state area.

31 **Setting:** A research laboratory at Moss Rehabilitation Research Institute.

32 **Participants:** One hundred ninety-four polio survivors were studied; demographic and  
33 medical history data, symptom data, and strength data were obtained for each.

34 **Main Outcome Measures:** Presence or absence of shoulder symptoms and ratings of pain by  
35 visual analogue scale (VAS) were recorded. Strength was measured using a hand-held  
36 dynamometer and manual muscle testing (MMT).

37 **Results:** Shoulder symptoms could be grouped into two distinct clusters based on the type of  
38 testing used for assessment. Symptoms elicited by palpation were present in 26% of the subjects  
39 and were strongly related to knee extensor strength and weight. These symptoms were more  
40 common among females than males (42% vs. 10%). Symptoms elicited by resistance tests were  
41 present in 33% of the subjects and were seen with equal frequency in both genders. These  
42 symptoms were also related to lower extremity strength, however the specific relationship was  
43 not as clear as for the palpation-related symptoms.

44 **Conclusions:** Lower extremity weakness predisposes individuals to shoulder overuse  
45 symptoms. Gender and body weight are contributing factors. These results may generalize to  
46 other populations with lower extremity weakness, including the elderly.

47 **INTRODUCTION**

48 The relationship between muscle weakness, overuse and injury is thought to be both a  
49 cyclical and a reciprocal one. Muscle weakness can produce overuse, overuse can lead to further  
50 weakness, and both can predispose to injury.<sup>1</sup> Overuse can occur directly when weakened  
51 muscles need to work harder to maintain a certain force or indirectly when alternate muscles are  
52 recruited to compensate for weak ones. Individuals can enter this weakness--overuse--injury  
53 cycle at different points and at different levels of weakness.

54 There are various etiologies of muscle weakness, but each may lead to overuse. Muscle  
55 weakness can occur as a result of lack of exercise (disuse), after an injury or illness, or as the  
56 result of a disease, such as polio. The resulting muscle weakness may be severe or mild. Often,  
57 individuals may not even be aware of mild muscle weakness. They may function and feel normal  
58 during their daily activities but might actually be overusing muscles to compensate for  
59 undetected "subclinical" weakness.

60 Because the muscle weakness experienced by many polio survivors is often quite  
61 significant, this population is susceptible to an accelerated pattern of overuse. Theoretically, this  
62 would allow the symptoms of overuse to be readily observed in a small population over a short  
63 period of time. For this reason, we hypothesize that the post-polio population provides an  
64 excellent model for the study of overuse disorders in the general population.

65 There are over one million polio survivors in the United States.<sup>2</sup> After recovering from  
66 the acute infection, survivors were left with varying degrees of muscle strength. As time passed,  
67 they became very adept at compensating for weakened muscles, with the end result being a  
68 higher risk of overuse and trauma to the compensating muscles as well as those muscles  
69 weakened by the initial polio.

70           Although the muscle weakness of the polio survivor is often more pronounced than that  
71 noted in the general population, polio is not a primary muscle disease. Normal muscle  
72 physiology, sensation and motor control are preserved.<sup>3</sup> It is thus a “pure” model for studying  
73 the effects of muscle weakness on the remainder of the musculoskeletal system.

74           Polio affected the lower extremities with twice the frequency of the upper extremities.<sup>4</sup>  
75 As a result, the most common complaints of polio survivors are related to issues of mobility.<sup>5</sup>  
76 For example, individuals with knee or hip extensor weakness may have difficulty with activities  
77 like climbing stairs or rising from a chair and often use their arms to assist with weight-bearing  
78 (e.g. to push off the armrests of a chair or pull up on a stair railing). We hypothesized that this  
79 behavior would lead to increased susceptibility to shoulder overuse and there would be an  
80 association between leg extensor weakness and shoulder overuse symptoms.

81           Previous studies have looked at the relationship of lower extremity weakness to various  
82 gait parameters and overuse of compensatory muscles in the legs among polio survivors.<sup>3,6</sup> There  
83 have also been studies on upper extremity overuse in individuals with paraplegia who must rely  
84 exclusively on their upper extremities for mobility.<sup>7,8</sup> However, to date, there have not been any  
85 studies which explored the potential relationship between lower extremity weakness and upper  
86 extremity overuse in an ambulatory population.

87           Therefore, the objective of this study was to explore the relationship between lower  
88 extremity weakness and upper extremity overuse among polio survivors, focusing specifically on  
89 shoulder symptoms and leg extensor strength. We predicted a curvilinear relationship between  
90 symptoms and strength (i.e. that the proportion of subjects with shoulder symptoms would be  
91 highest in the mid-range of leg extensor strength). These individuals would be more active than  
92 those with severe weakness and would put more stress on their arms during everyday activities

93 than those with mild or no noticeable weakness. We also predicted that shoulder symptoms  
94 would increase with age, weight and activity level and that the duration of time since the original  
95 polio infection would also be an important factor.

96

## 97 **METHOD**

### 98 **Subjects**

99 A total of 290 polio survivors were recruited from the Einstein-Moss Post-Polio  
100 Management Program and the community at large, including the surrounding four-state area:  
101 Pennsylvania, New Jersey, Delaware, and southern New York. The inclusion criteria were as  
102 follows: 1) a history of polio, 2) no major disabilities unrelated to polio that could cause  
103 weakness or overuse problems (e.g. stroke, amputation, inflammatory arthritis, peripheral  
104 neuropathy, muscular dystrophy, or congenital malformation), 3) no serious illnesses such as  
105 heart or lung disease which would make it unsafe for them to exert themselves in a strength test  
106 (e.g. severe emphysema, poorly controlled asthma, resting angina, recent heart attack, or recent  
107 treatment of an uncontrolled heart condition), and 4) no fractures or surgeries within the  
108 previous six months.

109 Of the 290 polio survivors initially screened, 194 participated in the study. Thirty-one  
110 individuals were excluded because they did not meet the inclusion criteria. The remaining 65  
111 individuals did not participate because of personal reasons (transportation problems, job  
112 conflicts, illness/death in family, etc.) or simply did not show up for one or more scheduled  
113 appointments. Ultimately, 98 men and 96 women were enrolled in the study. All subjects  
114 provided written informed consent prior to testing.

115

116 **Procedure**

117           The following protocol was approved by our Institutional Review Board. A brief clinical  
118 interview was conducted to review a standardized medical history questionnaire and a polio  
119 history form in which subjects specified their age at the time of the initial polio infection and  
120 identified any sites where they were left with residual weakness or paralysis. There were seven  
121 possible sites given: neck, back, abdomen, left arm, left leg, right arm, and right leg.

122           Each subject also completed a self-administered activity assessment survey, which was  
123 developed based on a questionnaire designed to measure habitual physical activity.<sup>9</sup> The survey  
124 included specific activities that might predispose to overuse symptoms and were divided into  
125 household, occupational, and recreational tasks. Under each heading, the tasks were broken  
126 down into upper limb activities (e.g. reaching, typing, sewing), lower limb activities (e.g.  
127 standing, walking, climbing stairs) and transfer activities (moving from sit to stand). For each  
128 activity, the subjects chose one of four levels that gave the best estimate of the frequency with  
129 which they performed that activity. Upper limb, lower limb, and transfer activity levels were  
130 then calculated by summing the frequency scores in each category.

131           After the forms were completed, height (cm) and weight (kg) were measured using a  
132 standard scale. A nurse then performed a symptom assessment, which included a combination of  
133 palpation and resistance tests of the biceps and supraspinatus. For the biceps palpation test, the  
134 shoulder was in neutral rotation, the elbow flexed at 90 degrees and the forearm supinated.  
135 Pressure was applied in the bicipital groove on the anterior shoulder. The arm was positioned in  
136 a similar way for the biceps resistance test, except the palm was down. The nurse then attempted  
137 to supinate the forearm while the subject resisted. For the supraspinatus palpation test, the arm  
138 was relaxed at the side and pressure was then applied on the tendon insertion site, just proximal

139 to the greater tuberosity of the humerus. Finally, for the supraspinatus resistance (impingement)  
140 test, the arm was held straight out at the side with the thumb pointing towards the floor. The  
141 nurse pushed on the arm above the elbow while the subject resisted.

142 If subjects reported feeling shoulder pain during a symptom test, they were asked if they  
143 had experienced pain in that area before and if they could identify the estimated date of onset  
144 (EDO) of the pain. They were also asked to specify activities that caused pain in the same area.  
145 Pain or tenderness identified as being related to the exam only (i.e. "It only hurts when you push  
146 there.") was not considered a potential overuse symptom and was not included in any of the  
147 analyses.

148 A manual strength examination was then performed by a physical therapist using a hand-  
149 held dynamometer (Empi Microfet2, St. Paul, MN). The physical therapist was masked from the  
150 results of the symptom assessment to prevent any potential bias. The bilateral hip extensor and  
151 knee extensor muscle groups were tested in gravity-eliminated postures. Bilateral shoulder  
152 flexion and abduction strength was also measured to account for the possibility that shoulder  
153 symptoms might be related to shoulder rather than leg weakness. The postures, placement of the  
154 dynamometer, and stabilization points were standardized (Table 1), along with the verbal  
155 encouragement used during the testing.

156 For each strength test, the subject pushed against the padded dynamometer force plate,  
157 which the physical therapist held stationary. The peak force was measured in pounds, and the  
158 range of the dynamometer was 0 to 100 lbs. Two measurements of peak force were taken for  
159 each muscle group. Additional measurements were taken only if the first two varied by more  
160 than 10% or by more than 1 lb. for strengths less than 10 lbs. The maximum number of  
161

162

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Insert Table 1 about here.

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164

165 measurements for a single muscle group was four to prevent fatigue. If a subject reported pain  
166 during testing, those trials were considered invalid. For each muscle group, the average of the  
167 valid trials was used for analysis. However, any muscle groups that did not have two trials that  
168 met the 10% or 1lb. criteria after four attempts were not included in any analyses.

169

170 In order for individuals to use their arms effectively to help push themselves out of a  
171 chair, they must have gravity-resistant strength in their elbow extensor muscles. Therefore, once  
172 the dynamometer testing was completed, the physical therapist performed manual muscle testing  
173 (MMT) on both elbow extensors using a standardized protocol as described by Kendall, and the  
174 Lovett grading system.<sup>10,11</sup> If the strength was equal to or greater than grade 3, it was specified  
175 using a plus (+) or a minus (-) sign to designate intermediary levels. If the strength was less than  
176 a grade 3, a muscle grade of <3 was recorded. Only subjects who had a minimum of grade 3  
177 strength in both elbow extensors were included in the symptom and strength analyses

177

### 178 **Reliability**

179 Two nurses and three physical therapists were involved in data collection for this study.  
180 Therefore, it was necessary to get a measure of inter-rater reliability for both the symptom and  
181 strength assessments.

182 Sixteen polio survivors were tested to determine symptom interrater reliability. Nurse #1  
183 performed the initial assessment for 10 of the subjects and Nurse #2 performed the initial  
184 assessment for the remaining 6 subjects. A period of one to five days separated the two

185 assessments for each subject. All assessments were done at the same time of day. . For  
186 symptom reliability,  $p_o$  or the proportion of observed agreement was calculated by taking the  
187 number of assessments when both nurses agreed divided by the total number of assessments for  
188 each of the four symptom tests. All values for  $p_o$  were above 93% except for the supraspinatus  
189 (impingement) test, which was 87%.

190 To determine the interrater reliability of the strength measurements, six subjects (2 polio  
191 survivors and 4 individuals with no history of polio) had their hip extensor, knee extensor,  
192 shoulder flexion, and shoulder abduction strength tested bilaterally by each of the three physical  
193 therapists. For each subject, all strength assessments were performed at the same time of day  
194 within a one month period. Intraclass correlation coefficients (ICC[3,1]<sup>12</sup>) were used as indices  
195 of reliability for the strength measurements. All ICC values were above 0.910 except hip  
196 extension on the dominant side, which was 0.787

197

### 198 **Statistical Analysis**

199 Data were analyzed using the SYSTAT7 software package. Subjects were classified  
200 based on whether they had a positive or negative response to each symptom test. In order to  
201 determine whether certain symptom tests were linked in their occurrence either by structure  
202 (biceps vs. supraspinatus) or type of test (palpation vs. resistance test), a correspondence analysis  
203 was performed. The results revealed two distinct clusters that were arbitrarily identified as  
204 Cluster 1 and Cluster 2. Subjects were then reclassified based on whether or not they had any  
205 Cluster 1 or Cluster 2 symptoms.

206 Biomechanically, there was no reason to believe that the symmetric/assymmetric use of  
207 the lower extremities was relevant to the production of shoulder symptoms. The knee extensors

208 work together to help lift a person off a chair, and the hip extensors work together to help the  
209 body straighten to a standing position. Therefore, we felt it was appropriate to consider  
210 combinations of the strengths of similar types of muscles in our analyses, including KNEES (the  
211 combined strength of both knee extensors), HIPS (the combined strength of both hip extensors),  
212 and ALL (the combined strength of both knee extensors and both hip extensors).

213 In order to determine the nature of the relationship between symptom status and the  
214 various independent variables (age, time since polio, weight, activity scores and the various  
215 strength measures), we converted the independent variables to quintiles (i.e. sorted each from  
216 smallest to largest and separated them into five bins with approximately the same number of  
217 subjects in each bin). The proportion of subjects in each quintile with either Cluster 1 or Cluster  
218 2 symptoms was then calculated. Plots of the proportion of subjects in each symptom cluster  
219 against the various independent variables (in quintiles) revealed neither a linear pattern nor a  
220 good fit to a polynomial equation. Therefore, the quintiles were treated as categorical variables  
221 (1-5). The only exception was weight. In the plot of the proportion of subjects with Cluster 1  
222 symptoms versus weight, we observed an increasing pattern. Therefore, this variable was  
223 treated as quantitative instead of categorical in the analyses for this symptom cluster. A Chi-  
224 square analysis was used to evaluate the effect of gender.

225 Because of the relatively large number of potential predictor variables, univariate logistic  
226 regression was performed to eliminate some terms prior to doing a multivariate stepwise logistic  
227 analysis. A cutoff value of 0.15 was used. In the multivariate analysis, the p-values were  
228 calculated relative to the highest level or quintile 5 for each independent variable. Odds ratios  
229 were calculated as a measure of the difference in the proportion of shoulder symptoms between  
230 quintile 5 and the other quintiles.

231 **RESULTS**

232 **Subject Characteristics**

233 The range in age for the study population was 32 to 81 years (mean age:  $57 \pm 10$  yr.).  
234 The median age at onset of polio was 5 years, and the median number of years since polio was  
235 48, ranging from 29 to 80 years. As expected, the most common sites for residual weakness  
236 were the legs (left (57%) and right (55%)). All of the remaining sites had values below 25%.  
237 Approximately 7% of the subjects stated that they had no residual weakness or paralysis.

238 A total of 15 (8%) of the subjects enrolled in the study did not meet the minimum  
239 requirements for elbow extensor strength (grade 3 or better in both arms). Therefore, their data  
240 were excluded from the strength and symptom analyses.

241

242 **Shoulder Symptoms**

243 Overall, 90 (46%) of the subjects had one or more shoulder symptoms. The  
244 correspondence analysis showed that there were two distinct symptom clusters. Cluster 1  
245 consisted of the four palpation tests (left and right biceps palpation and left and right  
246 supraspinatus palpation). Cluster 2 consisted of the four resistance tests (left and right  
247 supraspinatus (impingement) tests and left and right biceps tests). Replication of the  
248 correspondence analysis separately for each gender gave similar results. In both cases, the  
249 palpation-provoked symptoms formed one cluster and the resistance-provoked symptoms formed  
250 another.

251 There was no significant association between symptom clusters (Chi-square value =  
252 0.060, 1 d.f.,  $p = 0.806$ ). Overall, 30 (17%) subjects had palpation-provoked symptoms only, 43

253 (24%) subjects had resistance-provoked symptoms only, and 17 (9%) subjects had both types of  
254 symptoms.

255

### 256 **Palpation Symptom Analysis**

257 There was a significant association between gender and the presence of palpation  
258 symptoms (Chi-square value = 15.552, 1 d.f., p-value < 0.001). A total of 38 (42%) females had  
259 palpation symptoms compared to only 9 (10%) males. Because of the relatively low number of  
260 males with these symptoms, the remaining analyses were performed with females only.

261 The results of the univariate logistic regression analysis with presence or absence of  
262 palpation symptoms as the dependent variable, showed that weight, age, shoulder flexion  
263 strength, upper limb activity score, KNEES and ALL had p-values below the 0.15 cutoff. When  
264 these variables were put into a stepwise multivariate logistic regression analysis, the results  
265 showed that KNEES and weight were the best predictors of the presence of palpation symptoms  
266 among females. The p-values and odds ratios for the model are listed in Table 2.

267 A plot of the proportion of females with palpation symptoms versus KNEES (in  
268 quintiles) showed evidence of a threshold effect (Figure 1). The proportion of females with  
269 palpation symptoms was significantly higher when bilateral knee extensor strength was less than  
270 79 lb. than when it was greater than 79 lb. A plot of the proportion of females with palpation  
271 symptoms versus weight (in quintiles) revealed that as weight increased, the proportion of  
272 females with shoulder symptoms also increased (Figure 2).

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Insert Table 2 about here.

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Insert Figure 1 about here.

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Insert Figure 2 about here.

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283 **Resistance Symptom Analysis**

284 A Chi-square analysis showed no significant association between gender and presence of  
285 resistance symptoms (Chi-square value = 0.025,  $p = 0.999$ ), with an approximately equal  
286 proportion of symptomatic subjects for each gender (males: 33% and females: 34%). Therefore,  
287 we initially performed the logistic analyses with both genders combined.

288 The results of the univariate analysis, with presence or absence of resistance symptoms as  
289 the dependent variable, showed that HIPS, KNEES, ALL, and age all had p-values that were less  
290 than the cutoff level of 0.15. The results of the stepwise multivariate analysis showed that the  
291 model containing ALL and age best predicted the presence of resistance symptoms. The p-  
292 values and odds ratios for the model are summarized in Table 3.

293 A plot of the proportion of subjects with resistance symptoms versus ALL (in quintiles)  
294 showed that the highest proportion of symptomatic subjects was found in the mid-range for  
295 overall leg extensor strength (Figure 3). The plot of the proportion of subjects with resistance

296

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Insert Table 3 about here.

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297

298

299 symptoms versus age (in quintiles) showed that subjects between the ages of 50 and 54 years,  
300 had the highest proportion of symptoms (Figure 4).

301 Because of concern that gender was possibly confounding the results, the analysis was  
302 repeated on each gender separately. The results of the univariate analysis for males showed that  
303 KNEES and age were the only predictors with p-values less than 0.15. The stepwise multivariate  
304 analysis resulted in a model containing both variables. Plots of the proportion of males with  
305 resistance symptoms revealed that the highest proportion of symptomatic males were in the mid-  
306 range for both bilateral knee extensor strength and age. For females, the results of the univariate  
307 analysis showed that HIPS, ALL, and age had p-values less than 0.15. The stepwise multivariate  
308 analysis produced a model containing HIPS and age. The highest proportion of symptomatic  
309 females was on the low end for both bilateral hip extensor strength and age.

310 The odds ratios, sensitivity, and specificity values for the KNEES model and the HIPS  
311 model for both genders were compared (Table 4). For males, the KNEES model appeared to be  
312 the best predictor, with larger, more significant odds ratios and a higher sensitivity value model  
313 than the HIPS model. However, the HIPS model for males had a higher value for specificity  
314 than the KNEES model. For females, the odds ratios for both the knee and hip models show  
315 similar patterns, and the sensitivity and specificity values for both models are comparable.

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317 Insert Figure 3 about here.

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320 Insert Figure 4 about here.

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Insert Table 4 about here.

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324

325 **DISCUSSION**

326         The purpose of this study was to determine if there was a systematic relationship between  
327 leg extensor weakness and the presence of pain potentially attributable to shoulder overuse. The  
328 results showed that the shoulder symptom tests could be divided into two distinct clusters based  
329 on the type of testing used for assessment. The results of the multivariate analyses appear to  
330 support the theory that these are two different symptom complexes.

331         Palpation-provoked symptoms were more common among females, as are many overuse  
332 injuries.<sup>13,14</sup> This may be due to differences in pain perception and report. Previous studies have  
333 suggested men have a higher pain tolerance than women, especially in tests involving pressure  
334 pain.<sup>15,16,17</sup> These differences in pain sensitivity have been attributed to a variety of factors  
335 including differences in body size and skin thickness, sex-role expectations, and hormones. This  
336 may explain why we did not see a significant gender effect for resistance symptoms, which were  
337 assessed with an active motion test as opposed to someone applying pressure to a particular area.  
338 In order to determine if gender differences might simply be related to greater stoicism among  
339 men, we assessed the severity ratings for the resistance symptoms and found no significant  
340 differences (i.e. women did not rate their pain intensity higher than men).

341         Palpation symptoms among women were strongly related to knee extensor strength and  
342 weight. The most likely explanation is that weak knee extensors cause increased demand on the  
343 arms during tasks such as getting up from a chair or using an assistive device for ambulation.  
344 Increased weight will also result in an increased demand on the arms during similar tasks.

345 Unfortunately, we did not have sufficient power to allow us to distinguish a threshold model  
346 from the predicted curvilinear model. From the graph of the proportion of females with  
347 palpation-provoked symptoms versus quintiles of knee extensor strength, it did appear that the  
348 proportion of symptomatic females was highest in the mid-range for strength. However, it was  
349 not possible to determine whether females with moderate weakness were truly at higher risk for  
350 shoulder symptoms than profoundly weak subjects or whether this peak was simply due to  
351 random error.

352 In terms of predicting resistance symptoms, we were not able to draw any definitive  
353 conclusions. While it does appear that some aspect of lower extremity strength is a significant  
354 predictor for resistance symptoms for both genders, the results were variable between KNEES,  
355 HIPS and ALL, depending on which genders were included in the model. The results for males  
356 suggested that knee extensor strength is more important. However, for females the results were  
357 not as clear and there remains some doubt as to whether hip extensor, knee extensor strength, or  
358 some combination of both is the best predictor for females. Because of the high correlations  
359 between strength variables, a larger study is needed to determine which aspect of lower extremity  
360 strength is most important when predicting resistance symptoms and whether there are actually  
361 any gender-related differences.

362 Shoulder abduction strength was not found to be a significant predictor of shoulder  
363 symptoms in this population. Shoulder flexion strength met the cutoff criterion in the univariate  
364 analysis for palpation symptoms among females ( $p$ -value = 0.150), but was not selected in the  
365 stepwise multivariate analysis. Previous research on other populations has shown a relationship  
366 between weak shoulder muscles and shoulder symptoms in able-bodied adults (abductors and  
367 external rotators)<sup>18</sup> and in wheelchair athletes (adductors and internal rotators).<sup>19,20</sup> It is possible

368 that other shoulder strength measures such as adductor or internal rotator strength, which were  
369 not measured in this study, are related to shoulder symptoms in this population. However,  
370 despite this, the fact that knee extensor strength was a good predictor of shoulder symptoms  
371 provides support for our hypothesis that lower extremity weakness plays an important role in the  
372 production of shoulder symptoms in this population.

373 Age was an important factor for predicting resistance symptoms. We had predicted that  
374 duration of time since polio would be more important than chronological age in this population,  
375 but duration was not significant even at the univariate level. We had also predicted that  
376 symptoms would increase as age increased. However, the results showed that the proportion  
377 symptomatic subjects was highest among the younger females and the middle-age males in our  
378 study population. We speculate that these age levels may be most closely associated with the  
379 activity levels that provoke the symptoms.

380 In able-bodied populations, repetitive manual work is a known risk factor for shoulder  
381 symptoms.<sup>21,22</sup> A previous study involving 32 polio survivors reported that the experience of  
382 pain was related to level of physical activity.<sup>5</sup> In this study, we expected that lower limb  
383 activity level or transfer activity level would be an important factor in predicting the presence of  
384 shoulder symptoms. However, none of the activity levels were significant at the univariate level  
385 for resistance symptoms and only upper limb activity level was significant at the univariate level  
386 for palpation symptoms (p-value = 0.033). One possible explanation is that our activity  
387 questionnaire provided us with only a gross measure of upper and lower limb activity. In order  
388 to cover individuals with a wide range of strengths and activity levels, we were forced to make  
389 our questions as broad as possible. If we had limited our study to individuals with significant  
390 lower extremity weakness and concentrated more closely on activities performed by people at

391 this strength level, we expect that we would have found a stronger association between activity  
392 level and shoulder symptoms.

393 Another limitation of this study was that we did not have the power to test interactions  
394 between independent variables due to the relatively low percentage of subjects with each  
395 symptom cluster. More data are needed in order to capture the complicated synergisms that may  
396 exist between variables. For example, we would expect that there would be an interaction  
397 between strength and weight. Previous studies have documented that the amount of muscle  
398 strength required to perform daily activities increases as weight increases.<sup>23,24,25</sup> Weight was an  
399 important predictor for palpation symptoms along with overall knee extensor strength. We  
400 attempted to capture the interaction between knee strength and weight by calculating the ratio  
401 between the two variables (knee extensor strength divided by weight). However, our analysis  
402 showed that this ratio did not predict the presence of palpation-provoked symptoms as well as the  
403 model with weight and KNEES.

404 Future studies are needed in this area involving larger samples to better characterize the  
405 shapes of the distributions of symptom risk. Research involving other populations with varying  
406 levels of lower extremity weakness is also needed to determine if these results are generalizable  
407 to other groups. For example, the elderly are at high risk for lower extremity weakness due to a  
408 reduction in activity level and the decline in muscle strength associated with normal aging. In a  
409 sample of 58 subjects with no history of any neuromuscular disorders, aged 60 to 88 years, we  
410 found that 39% had bilateral knee extensor strength that was less than 79 lb. (unpublished data).  
411 According to our model, these people may be at high risk for development of shoulder overuse  
412 symptoms.

413 Biomechanical studies of the compensation patterns used by people with lower extremity  
414 weakness are also needed, both to identify the specific activity patterns and to determine whether  
415 there are actual gender differences. Finally, there is a need for studies which examine the  
416 effectiveness of therapies designed to either reduce the stress on the shoulders or increase the  
417 strength of the lower extremities as a way of preventing or reducing overuse symptoms in the  
418 shoulder.

419

## 420 **CONCLUSIONS**

421 The results of the present study indicate that there is a relationship between lower  
422 extremity weakness and shoulder symptoms. In this sample of polio survivors, knee extensor  
423 strength was identified as an important predictor of shoulder symptoms, with individuals with  
424 moderate weakness at highest risk. Body weight and age were also relevant factors. These  
425 results have important implications for people with significant levels of lower extremity  
426 weakness, who tend to increase their reliance on the upper extremities for mobility and activities  
427 of daily living. For these people, shoulder overuse problems can have a significant effect on  
428 quality of life. Additional research is needed to increase the awareness of the prevalence and  
429 impact of upper extremity overuse disorders in people with lower extremity weakness.

430

431 **Acknowledgments:** The authors would like to thank Roberta Costello, RN, Jeannine Jacobs,  
432 RN, Julie Nagorsky, PT, Christina Palmer, PTA, and Steve Sepel, PT for their assistance with  
433 data collection. We would also like to thank Yvonne Randolph for her help with recruiting and  
434 scheduling subjects. Finally, we gratefully acknowledge the time and effort of our research  
435 subjects without whom this research would not have been completed.

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504 **LEGENDS**

505 Figure 1 illustrates the relationship between knee extensor strength and the proportion of females  
506 with Cluster 1 (palpation) symptoms. Quintiles of strength among females are shown along the  
507 X axis, arrayed from weakest to strongest. The proportion of women with palpation-provoked  
508 symptoms in each quintile is shown on the Y axis.

509

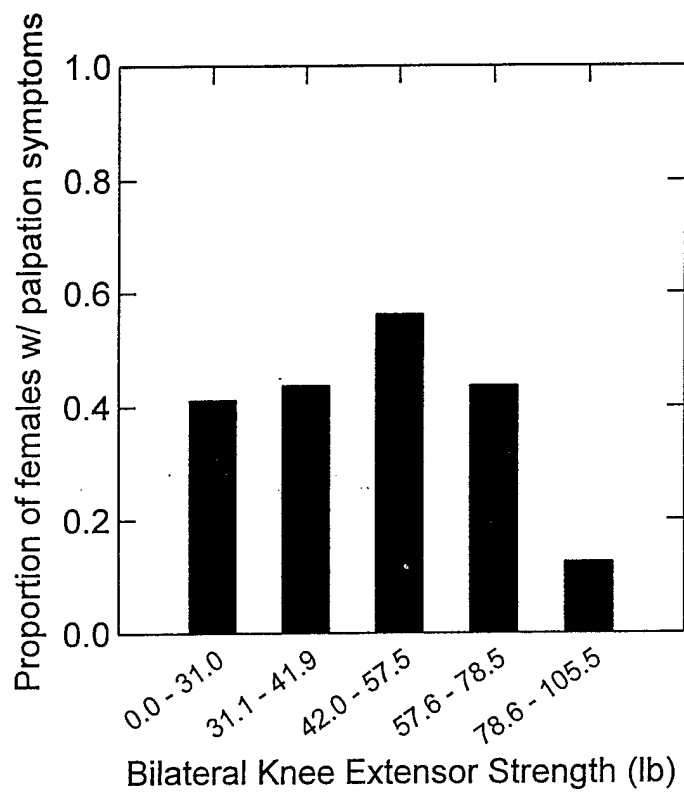
510 Figure 2 depicts the relationship between the proportion of females with Cluster 1 (palpation)  
511 symptoms and weight. Quintiles of weight, from lightest to heaviest, are shown on the X axis.  
512 The bars represent the proportion of women with Cluster 1 (palpation) symptoms in each  
513 quintile.

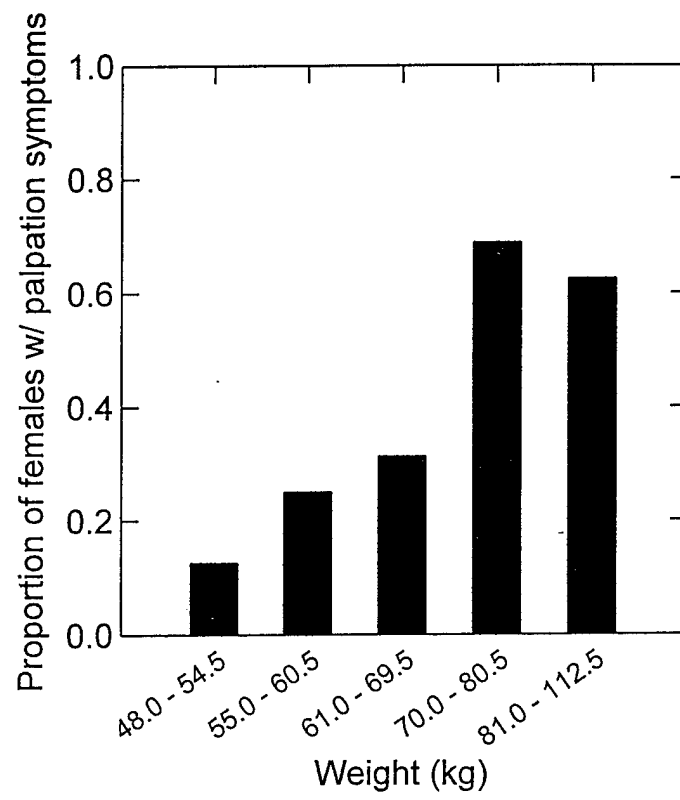
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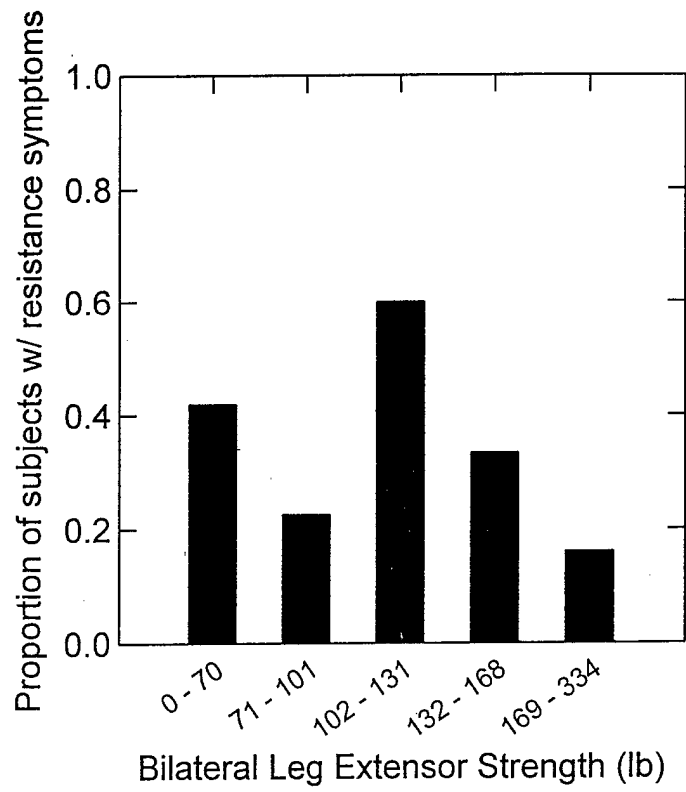
515 Figure 3 illustrates the relationship between overall leg extensor strength (ALL) and Cluster 2  
516 (resistance) symptoms. The quintiles of strength are arrayed from weakest to strongest along the  
517 X axis, and the proportion of subjects with resistance-induced symptoms in each quintile is  
518 shown on the Y axis.

519

520 Figure 4 illustrates the relationship between age and Cluster 2 (resistance) symptoms. The  
521 quintiles of age are ordered from youngest to oldest along the X axis. The bars represent the  
522 proportion of subjects in each quintile with resistance-induced symptoms.







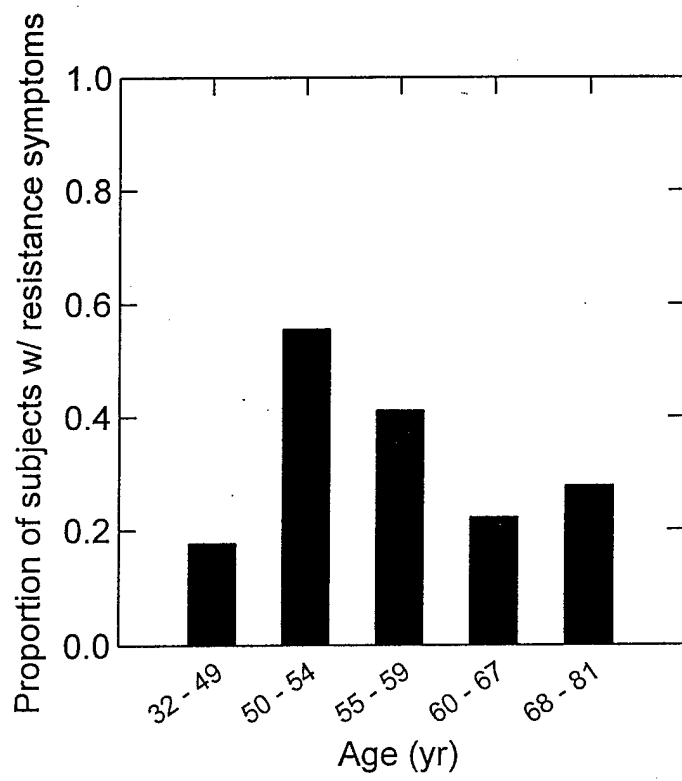


Table 1. Symptom Evaluation Protocol

<u>Test</u>	<u>Arm Position</u>	<u>Procedure</u>
Biceps palpation	Shoulder in neutral rotation; elbow flexed 90°; forearm supinated	Pressure applied in bicipital groove on anterior shoulder
Supraspinatus palpation	Arm relaxing at side;	Pressure applied on tendon insertion site just proximal to greater tuberosity of humerus
Supraspinatus (impingement) test	Arm straight out at side and internally rotated with thumb pointing towards floor	Examiner pushes on arm above elbow while subject resists
Biceps test	Shoulder in neutral; elbow flexed 90°; palm down	Examiner attempts to supinate forearm while subject resists

Table 2. Prediction of Shoulder Symptoms Provoked by Palpation

<u>Variable*</u>	<u>p-value</u>	<u>Odds Ratio</u>	<u>Confidence Interval</u>	
			<u>Upper</u>	<u>Lower</u>
Constant	0.000			
Weight	0.000	2.346	3.668	1.500
Knees - 1	0.014	13.454	107.589	1.683
Knees - 2	0.020	11.412	88.756	1.467
Knees - 3	0.006	18.526	146.600	2.341
Knees - 4	0.055	6.885	49.428	0.959

\*. variables are in quintiles

Table 3. Prediction of Shoulder Symptoms Provoked by Resistance Tests

<u>Variable*</u>	<u>p-value</u>	<u>Odds Ratio</u>	<u>Confidence Interval</u>	
			<u>Upper</u>	<u>Lower</u>
Constant	0.001			
All - 1	0.052	5.833	34.436	0.988
All - 2	0.376	2.308	14.717	0.362
All - 3	0.044	5.250	30.621	0.900
All - 4	0.065	6.000	34.317	1.049
Age - 1	0.442	1.634	5.709	0.467
Age - 2	0.036	3.916	13.988	1.096
Age - 3	0.985	1.012	3.787	0.271
Age - 4	0.185	2.337	8.215	0.665

\* variables are in quintiles

Table 4. Comparison of Regression Models

Model: KNEES and AGE

Model: HIPS and AGE

	Males	Females		Males	Females
<u>Variable*</u>	<u>Odds ratio</u>	<u>Odds ratio</u>	<u>Variable*</u>	<u>Odds ratio</u>	<u>Odds ratio</u>
KNEES-1	<b>7.269</b>	5.549	HIPS-1	3.995	<b>10.032<sup>†</sup></b>
KNEES-2	<b>3.952</b>	2.235	HIPS-2	2.798	<b>2.860</b>
KNEES-3	<b>22.218<sup>‡</sup></b>	4.838	HIPS-3	3.819	<b>5.793</b>
KNEES-4	<b>2.095</b>	4.870	HIPS-4	1.446	<b>6.406<sup>†</sup></b>
AGE-1	<b>2.154</b>	1.567	AGE-1	0.855	<b>2.845</b>
AGE-2	<b>16.396<sup>‡</sup></b>	3.399	AGE-2	3.979	<b>3.641</b>
AGE-3	<b>11.759<sup>†</sup></b>	0.310	AGE-3	4.050 <sup>†</sup>	<b>0.395</b>
AGE-4	<b>3.732</b>	1.215	AGE-4	1.245	<b>1.863</b>
Sensitivity	<b>0.758</b>	0.449	Sensitivity	0.435	<b>0.441</b>
Specificity	<b>0.507</b>	0.693	Specificity	0.702	<b>0.725</b>

Note: The models which resulted from the stepwise multivariate analysis are in bold.

\* - variables are in quintiles

† -  $p < 0.05$

‡ -  $p < 0.01$

TABLE 1. SUMMARY OF POST-POLIO RESEARCH

<u>Authors</u>	<u>Population</u>	<u>Length of Study</u>	<u>Muscle(s)</u>	<u>Results</u>
Dalakas et al.(1986) <sup>1</sup>	27 polio survivors* (symptomatic)	ave. of 8.2 yr. (range 4.5 - 20 yr.)	overall body score	annual decline of 1% in mean score
Munsat, Andres, and Thibideau (1987) <sup>5</sup>	6 polio survivors (symptomatic)	400 to 2100 days	unknown	no significant change in strength
Agre and Rodriquez (1990) <sup>6</sup>	23 polio survivors* 12 controls	2 yr.	biceps, hamstring, quadriceps	no significant change in any variables for either group
Agre and Rodriquez (1991) <sup>7</sup>	44 polio survivors* 38 controls	1 yr.	quadriceps (affected side only <sup>†</sup> )	no significant change in any measures for either group
Munin et al. (1991) <sup>9</sup>	7 polio survivors* (symptomatic)	3 yr.	quadriceps	29% increase on affected side, 14% increase on the nonaffected side
Grimby, Hedberg, and Henning (1994) <sup>2</sup>	20 polio survivors* (12 unstable and 8 stable)	4-5 yr.	quadriceps and hamstring (affected side only <sup>†</sup> )	significant decrease in all measures for unstable group; only for knee flexion in stable group
Agre et al (1995) <sup>3</sup>	78 polio survivors*	4 yr.	quadriceps and hamstring (affected side only <sup>†</sup> )	significant decrease in quadriceps strength only
Grimby, Kvist, and Grangard (1996) <sup>4</sup>	18 polio survivors*	4 yr.	quadriceps, hamstrings in 26 legs	total thigh muscle strength decreased 7.8% ± 2.9%
Ivanyi et al. (1996) <sup>10</sup>	56 polio survivors* (43 symptomatic and 13 asymptomatic)	ave. of 2.1 yr. (range 199 to 1070 days)	Shld. abductors and adductors; Elbow flexors and extensors; Wrist flexors and extensors; Hip abductors, adductors, and flexors; Knee flexors and extensors; Ankle dorsiflexors and plantarflexors	significant increase in strength in 10 out of 22 muscles for symptomatic group; significant decrease in 1 out of 22 muscles for asymptomatic group
Rodriquez, Agre, and Franke (1997) <sup>8</sup>	23 polio survivors* (11 unstable and 12 stable) 14 controls*	7 years	quadriceps (affected side only <sup>†</sup> )	no significant difference in rate of strength loss between groups

\* - all subjects were less than 65 years old at initial visit

† - if both legs affected, stronger one was tested

Table 2. Strength Testing Protocol

<u>Muscle Group</u>	<u>Body Position</u>	<u>Position of Limb</u>	<u>HHD Placement</u>	<u>Stabilization Point</u>
Shld. Ext. Rotation	Sitting	Shoulder at neutral; elbow flexed 90°	Just proximal to ulnar styloid	Contralateral shoulder
Shld. Abduction	Supine	Shoulder abducted 90°	Midshaft of humerus	Anterior aspect of shoulder
Shld. Flexion	Sidelying	Shoulder flexed 90°; elbow extended	Midshaft of humerus	Anterior aspect of shoulder
Shld Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to olecranon	Anterior aspect of shoulder
Elbow Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to ulnar styloid; dorsal surface of forearm	Shoulder
Elbow Flexion	Sidelying	Shoulder at neutral; elbow flexed 90°	Palmar surface of forearm; proximal to wrist	Shoulder
Wrist Flexion	Sitting	Shoulder at neutral; elbow flexed 90°	Dorsal aspect of hand	Forearm
Wrist Extension	Sitting	Shoulder at neutral; elbow flexed 90°	Palmar aspect of hand	Forearm
<hr/>				
Hip Abduction	Supine	Hip abducted to 45°; with contralateral hip neutral	Proximal to superior pole of patella on lateral aspect of thigh	Hip
Hip Flexion	Sidelying*	Hip flexed to 30°; knee flexed 60°	Proximal to superior side of patella	Pelvis
Hip Extension	Sidelying*	Hip neutral; knee extended	Proximal to popliteal crease	Pelvis
Knee Flexion	Sidelying*	Hip flexed 10°; knee flexed 30°	Proximal to malleoli on posterior aspect of calf	Anterior aspect of femur
Knee Extension	Sidelying*	Knee flexed 45°	Proximal to malleoli on anterior aspect of tibia	Femur
Ankle D. Flexion	Supine	Hip, knee, ankle at 0°	Metatarsals	Tibia
Ankle P. Flexion	Supine	Hip, knee, ankle at 0°	Metatarsal heads	Tibia

\* Leg positioned on raised powder board

Table 3. Characteristics of Subjects in Upper Extremity Group\*

<u>Variable</u>	Male Subjects	Female Subjects
	N = 32 <u>Mean (SD)</u>	N = 39 <u>Mean (SD)</u>
Present age (years)	57.84 (11.7)	56.31 (8.6)
Age (at onset of acute polio, years)	7.15 (6.3)	6.41 (6.5)
Height (cm)	175.40 (7.9)	162.19 (6.4)
Weight (kg)	86.77 (18.4)	70.07 (16.8)
<u>Strength (at initial visit, lb)</u>		
Left Shoulder External Rotator	20.23 (9.4)	15.70 (4.6)
Right Shoulder External Rotator	20.96 (7.8)	16.14 (4.8)
Left Wrist Flexor	23.06 (7.8)	16.50 (4.7)
Right Wrist Flexor	26.67 (6.4)	19.10 (5.0)
Left Wrist Extensor	26.69 (7.0)	17.92 (5.2)
Right Wrist Extensor	26.11 (6.7)	18.19 (5.8)
Left Shoulder Abductor	30.37 (13.1)	19.26 (6.2)
Right Shoulder Abductor	29.39 (13.3)	18.83 (6.6)
Left Shoulder Flexor	34.27 (14.3)	21.89 (5.5)
Right Shoulder Flexor	34.13 (12.0)	21.66 (6.8)
Left Shoulder Extensor	36.38 (13.3)	23.24 (6.0)
Right Shoulder Extensor	34.36 (12.2)	21.75 (6.7)
Left Elbow Extensor	31.50 (15.4)	23.67 (6.3)
Right Elbow Extensor	33.95 (8.6)	23.09 (6.8)
Left Elbow Flexor	44.19 (14.5)	28.53 (7.5)
Right Elbow Flexor	44.55 (12.4)	29.70 (9.3)

\* Reasons for excluding subjects from upper extremity group: 26 subjects had pain during testing, 17 subjects were missing data for one or more muscle groups, and 6 subjects had initial strength equal to zero in one or more muscle groups.

Table 4. Effect Sizes for Upper Extremity Muscles

<u>Muscle Group</u>	<u>Effect Size</u>
Right Wrist Flexor	1.109
Left Shoulder External Rotator	0.794
Left Elbow Extensor	0.758
Left Shoulder Extensor	0.719
Right Elbow Extensor	0.694
Right Shoulder External Rotator	0.670
Right Shoulder Extensor	0.525
Left Wrist Flexor	0.496
Left Shoulder Abductor	0.455
Right Shoulder Flexor	0.455
Left Wrist Extensor	0.448
Right Elbow Flexor	0.444
Left Elbow Flexor	0.421
Right Shoulder Abduction	0.391
Left Shoulder Flexor	0.310
Right Wrist Extensor	0.222

Table 5. Characteristics of Subjects in Lower Extremity Group\*

<u>Variable</u>	Male Subjects N = 30 <u>Mean (SD)</u>	Female Subjects N = 35 <u>Mean (SD)</u>
Present age (years)	57.93 (10.6)	54.80 (7.3)
Age (at onset of acute polio, years)	7.55 (6.2)	5.91 (6.2)
Height (cm)	177.10 (1.8)	163.14 (6.6)
Weight (kg)	84.17 (17.8)	71.10 (13.8)
<u>Strength (at initial visit, lb)</u>		
Left Hip Flexor	43.21 (13.8)	29.60 (10.3)
Right Hip Flexor	45.07 (13.1)	30.82 (10.2)
Left Hip Extensor	36.40 (11.7)	26.75 (8.9)
Right Hip Extensor	35.79 (11.6)	25.56 (8.4)
Left Hip Abductor	42.00 (13.0)	28.22 (8.6)
Right Hip Abductor	38.57 (12.4)	25.13 (7.7)
Left Knee Flexor	38.80 (16.1)	27.97 (11.5)
Right Knee Flexor	36.67 (13.2)	22.51 (9.7)
Left Knee Extensor	43.20 (20.7)	29.47 (13.1)
Right Knee Extensor	45.09 (18.8)	32.01 (15.5)
Left Ankle Dorsiflexor	32.45 (15.1)	25.40 (10.8)
Right Ankle Dorsiflexor	25.72 (13.6)	21.77 (10.6)
Left Ankle Plantarflexor	42.25 (16.8)	35.17 (14.7)
Right Ankle Plantarflexor	39.10 (19.2)	29.56 (14.2)

\* Reasons for excluding subjects from lower extremity group: 12 subjects had pain during testing, 13 subjects were missing data for one or more muscle groups, and 30 subjects had initial strength equal to zero in one or more muscle groups.

Table 6. Effect Sizes for Lower Extremity Muscles

<u>Muscle Group</u>	<u>Effect Size</u>
Left Ankle Dorsiflexor	1.050
Right Ankle Dorsiflexor	0.856
Left Knee Flexor	0.682
Left Hip Flexor	0.419
Right Hip Flexor	0.383
Right Knee Flexor	0.218
Right Knee Extensor	0.128
Right Hip Extensor	-0.024
Left Hip Abductor	-0.037
Left Hip Extensor	-0.083
Left Knee Extensor	-0.110
Right Hip Abductor	-0.130
Right Ankle Plantarflexor	-0.296
Left Ankle Plantarflexor	-0.368

Table 7. Comparison of Rate of Deterioration of Strength\*  
in Young and Old Polio Survivors  
Mean (SD)

<u>Muscle Group</u>	Young Group (40-50 yr.) <u>N = 18</u>	Old Group (60-70 yr.) <u>N = 17</u>	Mann-Whitney U <u>p-value</u>
Lower Extremity**	-0.031 (2.9)	-0.999 (3.1)	0.317
Left Hip Flexor	-2.314 (4.4)	-1.858 (3.1)	0.621
Right Hip Flexor	-1.055 (5.3)	-2.785 (3.9)	0.249
Left Knee Flexor	-2.507 (2.3)	-1.590 (2.4)	0.248
Right Knee Flexor	-0.520 (2.6)	-1.460 (4.5)	0.756
Left Ankle Dorsiflexor	-4.337 (3.7)	-4.820 (4.2)	0.644
Right Ankle Dorsiflexor	-2.446 (2.0)	-3.592 (3.2)	0.310

\* represented by robust slope calculated based on strength data from three visits

\*\* average slope across all lower extremity muscles