ANALYSIS OF THE EFFECT OF LOWER LIMB WEAKNESS ON PERFORMANCE OF A SIT-STAND TASK (DRAFT)

Mary G. Klein, PhD,1 Mukul Talaty, MS,2 Alberto Esquenazi, MD,2 John Whyte, MD, PhD,1 and Mary Ann Keenan, MD3

1Moss Rehabilitation Research Institute  
Korman Bldg. Suite 213  
1200 West Tabor Rd.  
Philadelphia, PA 19141

2Gait and Motion Analysis Laboratory  
MossRehab Hospital, Rm 323  
1200 West Tabor Rd.  
Philadelphia, PA 19141

3Neuro-Orthopaedic Program  
Albert Einstein Medical Center  
Willowcrest 4th floor  
5501 Old York Road  
Philadelphia, PA 19141

Abstract: The objectives of this research were: 1) to determine how the use of upper extremities to assist during a chair rise task affects lower extremity loading; 2) to examine how task difficulty affects performance when weakness is present; and 3) to compare the compensation strategies utilized by individuals with chronic weakness to those used by patients with acute weakness. Twelve polio survivors with predominant unilateral weakness of the knee extensors and six adults with no history of polio who had recently undergone unilateral knee surgery participated in this study. The sit-stand task was performed under four different conditions that varied by chair height and/or use of armrests. The results showed that the compensation strategies utilized by the polio survivors and surgery patients were similar, although the polio survivors showed a higher degree of asymmetric weight bearing, especially in the most difficult condition. These results may be helpful in predicting sites for future overuse problems.

1. INTRODUCTION

Use of the arms to compensate for weakness in the legs during weight-bearing activities, such as getting up from a chair or for stabilization while walking, is common and may be related to the development of shoulder pain and other symptoms of upper extremity overuse in people with lower extremity impairments (Klein et al., 2000; Bayley et al., 1987). Lower extremity muscle weakness can occur as the result of a disease, such as polio, or as the result of deconditioning after an injury or surgery. In order to develop effective interventions for treating overuse problems in people with lower extremity impairments, one must first understand the compensatory strategies that are employed when significant muscle weakness is present. Therefore, the objective of this research was to determine the compensatory strategies used during a sit-stand task in subjects with unilateral knee extensor weakness.

2. BACKGROUND

Rising from a chair is a common daily activity, and there is evidence to suggest it may actually be one of the most mechanically demanding functional tasks that people perform on a routine basis. Research has shown that standing from a seated position requires more leg strength and greater joint ranges of motion than walking or stair climbing. For example,
Hodge et al. (1989) used a pressure sensing instrumented hip endoprosthesis in vivo to show that rising from a chair yielded higher peak contract pressures than other activities like gait and stair ascent. Similarly, Berger et al. (1988) showed that rising from a chair produced greater knee torques than gait or stair-climbing.

Previous studies on sit-stand performance have identified a continuum of strategies for rising from a chair (Hughes et al., 1994). On one end of the spectrum is the momentum transfer strategy, where subjects use momentum generated by the trunk to aid in rising. At the other end of the spectrum is the stabilization strategy, where very little momentum is generated and movements that increase stability were utilized. In the middle are strategies that combine aspects of both the momentum transfer and stabilization strategies to differing degrees.

There is evidence that individuals employ a variety of compensatory changes in their chair rise strategy in response to changes in the sit-stand task. One example might be when the difficulty of the task is increased by lowering the seat height. Schenkman et al. (1992) showed that among healthy elderly subjects, the overall strategy for rising from the chair remained unchanged when seat height decreased, but the magnitude of the movement within the strategy increased. For example, in subjects who used the momentum transfer strategy, hip flexion angular velocity (a measure of momentum) increased as seat height decreased.

Compensatory changes in chair rise behavior may also occur as the result of a combination of changes in the task and changes in the person’s functional status. Hughes and Schenkman (1996) examined the changes in chair rise strategy in 18 moderately functionally impaired elderly as chair height decreased. The authors defined moderate functional impairment as the inability to descend four consecutive steps step-over-step without using the handrail and the inability to rise from a chair height of 33 cm. Subjects were asked to rise from a randomly order series of chairs that ranged in height from 0.33 cm to 0.58 cm in 5 cm. increments. They were not allowed to use their arms to assist. The results showed that there was a significant increase in peak hip flexion velocity and time to rise when comparing rising from the lowest successful chair to rising from a chair at knee height. Subjects simultaneously increased their momentum, while attempting to increase their stability by taking more time to rise. This strategy was less efficient than that used by healthy elderly subjects and therefore, less likely to be successful.

Lower extremity strength is an important variable that can limit the ability to rise from a chair. In particular, knee extensor strength is thought to be critical since the required knee extension moment is the largest of the lower extremity joint moments generated during chair rise (Schultz et al., 1992). The moment at the knee increases as chair height decreases (Rodosky et al., 1989). Hughes et al. (1996) evaluated chair rise mechanics in 11 functionally impaired elderly subjects (mean age: 78 + 8.1 yr.) and 10 healthy young subjects (mean age: 25 + 1.3 yr.). Similar to the study above, the subjects were not allowed to use their arms to help complete the task. The results of this study showed that the functionally impaired elderly subjects required 97% of their maximum isometric knee extensor strength to rise from their lowest successful chair height (ranged from 38 to 58 cm.), while the young subjects used less than 39% of their available strength at any chair height. Clearly, knee extensor strength can be a limiting factor in determining the ability to rise from a chair, especially in elderly individuals.

One of the limitations of these previous studies is that, for the most part, the analyses were limited to the sagittal plane. Therefore, left/right asymmetries could not be detected, which would be critical if the functional impairment was limited to only one side or one particular muscle. In addition, since the subjects were not allowed to use their arms to assist, the task may not be an accurate representation of the subjects’ normal behavior. Upper extremity strength can play an important role in sit-stand performance, particularly when there is some level of functional impairment in the lower extremities. Ellis et al. (1984) documented a 18.5% to 47% reduction in knee joint forces and muscle tensions when rising from a chair with the aid of arms compared to when rising without the aid of arms. Use of upper limbs to compensate for lower limb pathology is very common and can result in an increased risk of shoulder pain and disability (Gellman et al., 1988; Burnham, et al., 1993). Most of the studies that have focused on using the arms for weight-bearing have been limited to individuals who are wheelchair-bound and must rely exclusively on the their arms for mobility. Little information is available on the degree of upper extremity loading utilized during a sit-stand task by people who are ambulatory, but have significant weakness in one limb. Additional research is also needed on how chair rise strategies differ for people who have short-term, acute muscle weakness compared to people who have long term, chronic muscle weakness.

Therefore, the purpose of this study was to examine the compensation strategies used to perform a sit-stand task by subjects with unilateral knee extensor weakness. Our objectives were: 1) to determine how the use of upper extremities to assist during a chair rise task affects lower extremity loading; 2) to examine how task difficulty affects performance when weakness is present; and 3) to compare the compensation strategies utilized by individuals with chronic weakness to those used by patients with acute weakness. We hypothesized that the subjects would load more on their strong leg when rising from the chair in all conditions, and there would be less preferential loading when the chair was high than when the chair was low. When armrests were used, we predicted delayed loading of the lower extremities, but expected to see similar loading patterns for the two conditions at each chair height. We expected that the time to complete the chair rise would be
significantly affected by chair height and degree of knee extensor weakness, and that the subjects with acute weakness (surgery patients) would use their arms more than the subjects with chronic weakness (polio survivors) would. This would translate to an earlier time of peak arm force and a higher peak vertical arm force for the surgery patients than for the polio survivors.

3. METHOD

3.1 Subjects

The twelve polio survivors recruited into this study were from a pool of 194 post-polio subjects who participated in a previous study that examined the relationship between lower extremity muscle weakness and shoulder overuse symptoms (Klein et al., 2000). Muscle strength was measured in the bilateral hip and knee extensors using a traditional manual muscle testing method (Lovett and Martin, 1916). Muscles were graded using scores ranging from 0 to 5. Strength was also measured using a hand-held dynamometer. Details on the positioning and stabilization used for each muscle group are available elsewhere (Klein, et al., 2000). In order to qualify for this study, the post-polio subjects had to have at least one full muscle grade difference between their left and right knee extensors. In addition, six adults with no history of polio, who had unilateral knee surgery (i.e. arthroscopy) within the previous 4-8 weeks, were recruited from the orthopedic practices of the Albert Einstein Medical Center. Hip extensor and knee extensor strength were measured in the surgery patients using the hand-held dynamometer. To qualify for the study, the surgery patients were required to have a minimum of a 10 lb. difference in knee extensor strength between the limb where the surgery was recently performed and the unaffected limb. All subjects were screened to ensure that none of them had any major disabilities unrelated to their polio or recent surgery that could affect the pattern of muscle use during the research task (e.g. acute back pain, peripheral neuropathy, diabetes, amputation, stroke, inflammatory arthritis, or muscular dystrophy). In addition, all subjects had to be able to stand up from a chair safely. Potential subjects who were unable to use their arms to help push out of a chair were excluded.

Written informed consent and permission to videotape the testing session were obtained from all subjects, and the hospital’s institutional review board approved the study protocol.

3.2 Procedure

Anthropometric parameters (i.e. limb/segment lengths and circumferences) of both lower and upper extremities were measured using calipers and measuring tape. Height (cm) and weight (kg) were measured using a standard scale. Selspot kinematic markers (light emitting diodes or LEDs) were placed in a standard configuration over various anatomical landmarks for measurement of body motion during the sit-stand task. Twenty-four markers were used. A foot wand containing two LEDs was positioned over the second metatarsal space of the foot. Markers were also placed on the lateral maleolus, the estimate of the anatomical knee center, and the trochanter. Wands were placed on the midspan of the lateral aspect of the tibia and the midspan of the lateral aspect of the femur. A rigid array of markers was placed over the posterior aspect of the pelvis. For the upper extremities, a trunk rigid array was supplemented with individual markers on the wrist, forearm, and upper arm. Data was sampled at 62.5 Hz. A video record was taken to correlate quantitative differences in the pattern of motion.

The subjects performed the sit-stand task under four different conditions. These conditions varied in terms of chair height and whether or not the subjects were allowed to use the armrests and were as follows:

- a) A standard height chair (45.5 cm) without use of armrests (referred to as low, no armrests condition, or LWA)
- b) A standard height chair (45.5 cm) using armrests (referred to as low with armrests condition or LNA)
- c) An elevated chair (55.5 cm) without use of armrests (referred to as high, no armrests condition or HNA)
- d) An elevated chair (55.5 cm) using armrests (referred to as high with armrests condition or HWA)

The order in which each task condition was performed was randomized. Subjects were encouraged to accomplish each task at their own pace. The chair rested on a platform that was positioned over a pair of extra large force plates that allowed natural placement of the foot on each force plate. For all the conditions, subjects were told not to place their hands on the chair seat. If, in conditions (a) or (c), the subjects were unable to get out of the chair successfully either by having their arms hang at their sides or by throwing their arms forward, they were allowed to place their hands on their thighs or knees to assist themselves. In conditions (b) and (d), the subjects were asked to place their hands on the armrests prior to beginning the sit-stand maneuver. A pressure switch affixed to the seat was used to determine lift-off from the chair. The arms of the chair were instrumented with triaxial load cells in order to measure the forces placed upon them as the subject...
performed the tasks. For each condition, the subjects performed the sit-stand maneuver 4 to 8 times. Subjects were given adequate time to rest, as needed, between trials and conditions.

4. DATA ANALYSIS

Matlab 5.0, Systat 7.0 and Microsoft Excel software were used for data processing and analysis. Prior to analysis, the leg and arm force data were normalized to percent of body weight. The beginning of the cycle time was defined as when the subject initiated forward head movement, and the end of the cycle was defined as when the subject reached full standing height. For the purposes of consistency, each subject’s “weak side” was defined as the side of the body where the weak knee extensor was located. Means and standard deviations for peak vertical leg force, time of peak vertical leg force, peak vertical arm force, timing of peak vertical arm force, peak anterior-posterior trunk velocity and peak vertical trunk velocity were calculated for each sit-stand condition.

Initially, a repeated measures multivariate analysis of variance (MANOVA) was run on each of the force and timing variables, separately for each leg, with condition and trial as the repeating factors and group (polio vs. surgery) as the grouping factor. Since the results showed no evidence of any practice or fatigue effects between trials for any of the force or timing variables, the average of each variable across trials in each condition was used in the remaining analyses.

The effect of leg (weak vs. strong), chair height (high vs. low), and armrest (use vs. no use) on the force and timing variables were assessed with repeated measures MANOVAs, with group (polio vs. surgery) as the grouping factor. Post-hoc testing of group differences was performed using the Mann-Whitney U test. Spearman correlational analyses were run in order to determine whether any of the strength variables or combinations of these variables were related to the peak anterior-posterior (A-P) velocity or peak vertical velocity. Statistical significance for all analyses was defined as p < 0.05.

5. RESULTS

5.1 Subject Characteristics

The descriptive characteristics of the subjects are given in Table 1. Six of the post-polio subjects had predominant left-sided knee extensor weakness, and the remaining six post-polio subjects had predominant right-sided weakness. Similarly, three surgery subjects had knee surgery on the left side and the three had knee surgery on the right side. There were no significant differences between groups for age or any of the strength variables, except for knee strength on the weak side (Mann-Whitney U test, p < 0.001)

5.2 Peak Vertical Leg Force

Results of the repeated measures MANOVA on peak vertical leg force showed a significant leg effect. There were higher peak vertical forces under the leg on the strong side than under the leg on the weak side in all conditions (i.e. the kinetic demands for rising out of the chair were shifted from the weak extremity, as predicted). Although both populations showed evidence of a shift in body weight towards the strong leg, this shift was much more apparent in the postpolio group than in the surgery group. The results also showed a significant leg by height interaction (p = 0.014). For the leg on the weak side, the peak vertical force was greater when the chair was high than when it was low. The opposite was true for the leg on the strong side. In other words, there was less of a difference between the peak vertical forces in each leg when the chair was high, which translates to less preferential loading at this chair height. The main effect of armrest (use vs. no use) was also significant (p < 0.001). Use of the armrests to help bear some of the weight while rising from the chair reduced the amount of force applied to the legs. This difference was greater in the leg on the strong side than in the leg on the weak side, which would be expected since the leg on the strong side was bearing the majority of the weight in the “no armrest” conditions. However, the height by armrest interaction was not significant (p = 0.361), indicating that this pattern of the peak vertical force in the legs being higher when armrests were not used was similar for both chair heights. In the two conditions where armrests were not used, the difference in the peak vertical forces between legs in each condition was correlated with the strength in the knee extensor on the weak side (Spearman correlation: LNA condition: r = -0.596, p = 0.009; HNA condition: r = -0.587, p = 0.010). As the strength in the knee extensor on the weak side increased, the difference in the peak vertical force between legs decreased. None of the correlations for the other strength variables were significant for any of the conditions (all p > 0.05).
Table 1. Subject Characteristics*

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Weak Hip Strength (lb)</th>
<th>Strong Hip Strength (lb)</th>
<th>Weak Knee Strength (lb)</th>
<th>Strong Knee Strength (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postpolio</td>
<td>12</td>
<td>7 M, 5 F</td>
<td>51.5 (7.7)</td>
<td>22.9 (9.6)</td>
<td>33.0 (4.8)</td>
<td>8.3 (7.8)</td>
<td>38.8 (13.0)</td>
</tr>
<tr>
<td>Surgery</td>
<td>6</td>
<td>3 M, 3 F</td>
<td>48.8 (15.7)</td>
<td>34.5 (18.2)</td>
<td>34.9 (17.0)</td>
<td>43.2 (18.7)</td>
<td>52.8 (16.6)</td>
</tr>
</tbody>
</table>

* Mean (SD)

5.3 Time to Complete the Sit-Stand Task

The mean times to complete the sit-stand task for each group and test condition are summarized in Table 2. The results of the repeated measures MANOVA analysis showed a significant main effect of chair height (p = 0.005), with the time to rise in the “low” conditions greater than the time to rise in the “high” conditions. The main effect of group was not significant (p = 0.240), although there was a trend for the postpolio subjects to get up faster than the surgery subjects.

5.4 Peak Vertical Arm Force

If subjects with acute weakness (surgery patients) use their arms more than subjects with chronic weakness (polio survivors), we would predict that there would be a significant difference in the peak vertical arm between groups (Table 2). Unfortunately, due to a malfunction in the load cells that were mounted in the armrests, valid arm force data was not obtained for three of the surgery patients. Since this left only three surgery subjects with valid arm force data, statistical between-group comparisons were not possible. By visual observation, the data do not appear to support our prediction. In fact, the force under the weak arm appears to be nearly equivalent for both groups. On the strong side, it is the postpolio group that has higher levels of force.

Within the polio group, there was a significant difference between the amount of force applied under each arm, with more force under the arm on the “strong” side. The results of the repeated measures MANOVA showed a significant main effect of armrest (p = 0.001), with more force being applied under the arm on the “strong” side. The main effect of chair height was also significant (p = 0.002) with the post-polio subjects loading both arms more in the low chair condition than in the high chair condition. The peak vertical force under both arms was significantly correlated with the hip extensor strength on the “strong” side in the low chair condition (arm on weak side: Spearman r = 0.697, p = 0.012; arm on strong side: Spearman r = 0.509, p = 0.20).

5.5 Peak A-P and Vertical Trunk Velocities

The analysis of the maximum anterior-posterior (A-P) trunk velocity revealed higher levels in the LNA condition than in the other conditions. This velocity is produced during forward trunk flexion, and is a measure of the momentum the subject generates to propel his/her body out of the chair. This velocity was calculated by numerically differentiating the position data from an array of markers placed on the trunk. A repeated measures MANOVA was run with chair height and armrest use as the repeating factors, and group (post-polio vs. surgery) as the grouping variable. The results showed a significant main effect of chair height (p < 0.001). In both armrest conditions, the A-P velocity was higher for the lower chair height, as predicted. The same pattern was seen for both surgery and post-polio subjects.

The results of the correlational analysis showed that in the LNA and HNA conditions, A-P velocity was significantly correlated with hip extensor strength on the strong side (LNA Spearman: r = 0.531, p = 0.023; HNA Spearman: r = 0.617, p = 0.006). In both conditions, the A-P velocity increased as the hip extensor strength on the strong side increased. Within each condition, the A-P velocities were not significantly different between the post-polio and surgery groups, except in the LNA condition. In this case, the post-polio group had a significantly higher forward velocity than the surgery group (Mann-Whitney U test statistic = 4.000, p = 0.049).

A similar analysis was run on peak vertical or upward velocity. The results showed that this velocity was significantly affected by chair height (i.e. the velocity in the “low” conditions was higher than in the “high” conditions for both groups) and armrest use (i.e. the velocity in the conditions with armrests was lower than in the conditions without armrests). Unlike the peak A-P velocity, which was correlated with hip extensor strength on the strong side, peak vertical velocity was
Table 2. Summary of Results for Each Sit-Stand Condition*

<table>
<thead>
<tr>
<th>Group</th>
<th>Condition</th>
<th>Time to Complete Task (sec)</th>
<th>Peak Leg Force (% of BW)</th>
<th>Peak Arm Force (% of BW)</th>
<th>Peak A-P Velocity (m/sec)</th>
<th>Peak Vertical Velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postpolio</td>
<td>LNA</td>
<td>1.44 (0.20)</td>
<td>Strong: 86.4 (8.1)</td>
<td>--</td>
<td>1.04 (0.21)</td>
<td>0.57 (0.19)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 26.0 (8.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
<td>1.56 (0.41)</td>
<td>Strong: 65.7 (7.5)</td>
<td>--</td>
<td>0.83 (0.21)</td>
<td>0.58 (0.16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 45.5 (10.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postpolio</td>
<td>LWA</td>
<td>1.39 (0.20)</td>
<td>Strong: 70.4 (12.0)</td>
<td>Strong: 27.3 (5.1)</td>
<td>0.74 (0.16)</td>
<td>0.65 (0.15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 37.7 (9.8)</td>
<td>Weak: 22.1 (5.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
<td>1.55 (0.13)</td>
<td>Strong: 62.1 (7.3)</td>
<td>Strong: 20.6 (4.5)</td>
<td>0.62 (0.16)</td>
<td>0.52 (0.16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 37.7 (9.8)</td>
<td>Weak: 20.6 (3.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postpolio</td>
<td>HNA</td>
<td>1.33 (0.20)</td>
<td>Strong: 82.9 (10.2)</td>
<td>--</td>
<td>0.81 (0.22)</td>
<td>0.46 (0.14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 28.0 (12.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
<td>1.35 (0.19)</td>
<td>Strong: 63.3 (6.8)</td>
<td>--</td>
<td>0.74 (0.13)</td>
<td>0.45 (0.15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 44.3 (9.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postpolio</td>
<td>HWA</td>
<td>1.32 (0.26)</td>
<td>Strong: 66.0 (9.1)</td>
<td>Strong: 23.6 (4.7)</td>
<td>0.59 (0.15)</td>
<td>0.42 (0.16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 28.4 (11.9)</td>
<td>Weak: 18.9 (5.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
<td>1.49 (0.15)</td>
<td>Strong: 58.3 (7.5)</td>
<td>Strong: 19.8 (5.7)</td>
<td>0.58 (0.15)</td>
<td>0.40 (0.14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Weak: 41.3 (8.6)</td>
<td>Weak: 19.0 (5.6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Mean (SD)

correlated with knee extensor strength on the strong side (Spearman: r = 0.634, p = 0.005). Subjects with stronger knee extensors on their “strong” side had a higher peak vertical velocity than those with weaker knee extensors. However, there was no significant difference in peak vertical velocity between post-polio and surgery groups in any of the four conditions.

6. DISCUSSION

Overall, the compensation strategies utilized by both the subjects with acute knee extensor weakness (surgery) and the subjects with chronic knee extensor weakness (polio) appeared very similar. The major difference was that these compensation effects were more apparent in the post-polio group than in the surgery group, especially in the LNA condition (i.e. the most difficult condition). The postpolio subjects showed a higher degree of asymmetric body weight bearing. This is important implications for the development of overuse symptoms. Habituation of the uneven body weight distribution can lead to overuse problems, particularly in the arm and shoulder on the strong side, as well as in the muscles in the strong leg that are having to work harder to compensate for the weak muscles in the other leg. However, despite the more asymmetrical loading pattern and the higher degree of weakness, there was a trend for the post-polio subjects to get out of the chair more quickly than the surgery subjects. This would tend to support the hypothesis that polio survivors have a more developed compensation strategy or mix of strategies. Polio survivors have had to deal with their muscle weakness for many years compared to the surgery subject who have had their knee weakness for only a few weeks. These strategies help the polio survivors perform the sit-stand tasks more quickly and efficiently than the surgery subjects, despite their higher levels of muscle weakness.

The subjects employed several strategies to accomplish the chair rise task, including simply changing the body segments that were used to meet the force demands. Often times, this was accomplished by changing the position of one or more body segments, such as placement of the feet. Other strategies included more judicious use of the inertial and momentum parameters, such as using increased forward velocity of the head-arms-trunk (HAT) segment to assist in overcoming the
task demands. The mean peak A-P of forward velocity was highest in the LNA condition, supporting the assumption that the task would be more difficult to perform in this condition than in any of the others.

Another strategy used by some of the subjects was using the arms to push off of the thighs or knees when they were not allowed to use the armrests (50% of the post-polio subjects and 16.7% of the surgery patients used this method to get out of the lower chair). On average, subjects who pushed off were weaker than those who didn’t. As expected, the peak A-P or forward velocity was lower for subjects who pushed off than in those who did not. Another compensation strategy that was utilized was increasing the amount of hip flexion prior to lifting the body off the chair. Subjects leaned forward more when the chair height was lower. This height effect was much more significant in the post-polio group than in the surgery group.

One of the limitations of this study was the lack of an age-matched control group with no muscle weakness. When defining the specific “compensatory behaviors”, it would have been helpful to have measures of so-called “normal behaviors” for the same task conditions. For example, in previous sit-stand studies involving young, healthy subjects lower extremity bilateral symmetry is often assumed. However, this may not always be the case. In a study involving healthy adult subjects with no muscle weakness, Rodosky et. al. (1989) documented consistent right-left asymmetries during rising from several chair heights. Nine out of 10 of these subjects were right-handed, and the authors speculated that their right-sided dominance might impart differences in proprioception and balance between the right and left lower extremities, resulting in a slight shift of body weight towards the right side when rising from a chair. In the current study, all 12 of the polio survivors were right-handed and all but one of the surgery patients were right-handed. If no weakness was present in any of these subjects, we might have expected to see a slight shift to the right-side. Instead, what we found was that the subjects with unilateral knee extensor weakness both acute and chronic, put more weight on their stronger leg when performing a sit-stand task. They also tended to bear more weight on the arm on the strong side, indicating a shift in the body’s center of mass towards the unaffected side. This shift was much more significant in the lower chair conditions than in the high chair conditions and was more significant in the polio survivors than in the surgery patients. Similar results have been documented for stroke patients. Engandt and Olsson (1992) reported that hemiplegic patients spontaneously and constantly put more body weight on the nonparetic leg when getting up from and sitting down on a chair.

An additional limitation of this study was the small sample size, making generalization of the results difficult. In addition, although the post-polio subjects had one knee extensor that was significantly weaker than the other, their muscle weakness was not limited to this muscle group. All but one of the post-polio subjects also had significant weakness in one or more other lower extremity muscles including, but not limited to, the hip extensors and/or ankle plantar flexors on both their “strong” and “weak” sides. However, the difference between the two sides for these other muscles was not as predominant as the difference between the knee extensors.

Lastly, another potential limitation of this study was that the task was not well-controlled. For example, subjects were allowed to place their hands and feet wherever they were most comfortable. As a result, there was a tremendous amount of variability in body/limb positioning, chair rise strategy, etc. among subjects. We would argue that, while controlled protocols of sit-stand performance can provide important information regarding differences of capability between subject groups, uncontrolled protocols, like the one used in this study, provide useful information regarding the adaptations that different subject groups might make in response to changing task difficulty. The requirement of standard, non-preferred positioning would have placed additional demands upon the subjects when the movement was executed, which may have caused them to modify their task performance. By allowing the subjects to choose the position and the chair rise strategy that worked best for them, we were able to get a better idea of the range of compensations that individuals utilize depending on the difficulty of the task involved.

Given that individuals with lower extremity weakness employ a variety of compensatory mechanisms to redistribute mechanical loads among joints during functional activities, the long-term consequences of these compensatory mechanisms is an important issue for further investigation. At least two aspects of the compensatory strategies employed by the subjects in the current study may have important clinical implications. First, the long-term effects of the increased stress on the joints in the upper extremities need to be considered. Problems related to overuse have been documented in paraplegics, who must rely exclusively on their upper extremities for mobility (Gellman, et. al., 1988; Burnham, et., al., 1993). However, additional research is needed to determine the effects of using the arms for weight-bearing in populations such as the frail elderly, who may have significant lower extremity weakness as the result of aging. Secondly, the reduction in muscle forces and resultant joint torques on the affected side can result in problems related to disuse. This can potentially lead to atrophy and further weakening of the knee muscles. Further studies are needed to explore the consequences of the altered joint dynamics in individuals with unilateral knee weakness and other types of lower extremity muscle impairments.
7. CONCLUSIONS

The results of this study provide some insight into the biomechanical strategies used to compensate for knee extensor weakness and may be helpful in predicting sites for future overuse problems. The analysis of the strategies used by patients with significant knee weakness in a sit-stand task can be used in the design of future trials to assess the efficacy of various rehabilitative treatments. In addition, a better understanding of the underlying dynamics of compensatory maneuvers may be helpful to clinicians in diagnosing the degree or distribution of muscle weakness in patients who exhibit such behaviors.

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9. REFERENCES


