Effects of Body Mechanics Training on Performance of Repetitive Lifting

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Key Words: back injuries • work hardening

Objective. To measure the efficacy of body mechanics instruction (BMI) in patients with low back pain.

Method. The effect of BMI was measured in four participants with back injuries using a standardized lifting protocol. Static strength, weight lifted, number of lifts completed, and motion analysis data to describe the body mechanics were measured before and after work hardening to evaluate treatment effects. The participants’ performances were compared with 52 controls from an earlier study.

Results. Starting postures, characterized by degrees of hip and knee flexion, varied by participant but favored a squat lift in three participants when compared with the controls. Dynamic motion synchrony of the hip and knee joints was similar to controls in three of the four participants. Posttest data revealed significant changes in static strength, dynamic endurance, and lifting speed.

Conclusion. Intensive instruction in body mechanics provided during the work-hardening treatment produced major changes in lifting styles, in terms of both starting postures and dynamic aspects of repetitive lifting. The computerized measurement procedures used in this study permitted more careful and detailed analyses of body mechanics, particularly dynamic aspects, than is possible with observational methods. This study demonstrated some of the inherent intricacies in isodynamic lifting and suggests additional areas of performance that may be important to address in BMI.


Chronic back pain is a costly and elusive problem. Claims of low back pain are the source of 40% of workers’ compensation losses, and they account for 15% to 25% of all work-related injuries (Volinn, VanKoevering, & Loeser, 1991). Various rehabilitation-oriented interventions such as pain management, functional restoration, and work-hardening programs have been developed to address both the physical and psychological factors contributing to chronic pain disability. These programs use a multidisciplinary team to evaluate and treat the multifaceted experience of chronic pain (Fordyce, 1995), in part because the application of the traditional medical approaches (i.e., medication, surgery) has not been effective in addressing back pain.

The role of occupational therapy within these rehabilitation programs appears consistent: It focuses on the assessment and treatment of functional capacities. Flower, Naxon, Jones, and Mooney (1981), Giles and Allen (1986), Padilla and Bianchi (1990), and Strong (1987) described the use of instruction in work simplification and body mechanic techniques to inhibit the exacerbation of pain and
facilitate productive involvement in routine activities of daily living. Hazard et al. (1989) reported the use of general training in frequent and sustained lifting, pushing and pulling, and prolonged postural maintenance of sustained positions or postures in a functional restoration program. Matheson, Ogden, Violette, and Schultz (1985) and Ogden-Niemeyer and Jacobs (1989) also described instruction in body mechanics and pacing of activities as effective methods for symptom control and enhanced productivity during a work-hardening program.

Instruction in body mechanics is based on studies that examine the effects of mechanical stress or loading on the supporting and controlling structures of the spine. The mode of loading may be tension, compression, bending, shear, and torque or a combination of these forces resulting from the dynamic nature of performing functional tasks (Lindh, 1989). The loading may cause deformation and, with repetition, lead to the deterioration of the structure(s). Trauma from a single incident or from cumulative effects to one or a combination of the spinal structures can produce nociceptive input, which is usually perceived as pain. Therefore, it is theorized that body mechanic principles can reduce nociceptive stimulation by decreasing mechanical stress and, therefore, can serve as an effective tool for pain management (Kahlil, 1993).

Despite the importance that clinicians have ascribed to instruction in proper body mechanics (Demers, 1992; Ogden-Niemeyer & Jacobs, 1989), the outcome of this intervention has not been widely examined. The application of body mechanics principles to a functional activity encompasses the combination of postures and movements needed to initiate, sustain, and complete the task. Carlton (1987) used a 17-item checklist to evaluate the transfer of body mechanics instruction (how to lift, lower, and transfer objects) received in the clinic to the performance of job duties within the work environment for food service employees. McCauley (1990) measured the effects of body mechanics instruction (how to lift, lower, pull, and transfer objects) on young workers’ performance of job duties in the workplace by recording observations on a criterion-referenced checklist. The results indicated that the group that received instruction performed significantly better than the control group.

Although observation checklists and rating scales may be appropriate tools for measuring changes within the psychomotor domain (e.g., Seels & Glasglow, 1990), these instruments are limited when measuring a complex dynamic task such as lifting. They only give credit for demonstrating the desired components of lifting without also considering the size of the participant or the environmental circumstances. However, according to Parnianpour, Bejjani, and Pavlidis (1987), the safest lifting techniques are situation dependent. Furthermore, it is unlikely that a checklist can detect subtle changes in spinal alignment, such as the presence or absence of lordosis. Lastly, these instruments may not have established reliability or validity or sufficient sensitivity to detect the subtle changes in task performance associated with fatigue during a sustained dynamic activity (e.g., changes in body angles to redistribute the work load among muscle groups). A basic limitation in measuring lifting technique by starting position alone is the inability to describe the coordination patterns used to execute the task (Boston, Rudy, Mercer, & Kubinski, 1993; Scholz, 1992).

The purpose of this study was to evaluate the efficacy of body mechanics instruction through the use of dynamic measurement instruments with proven reliability, validity, and ability to discriminate between persons with chronic low back pain and persons without such pain.

Method

Participants

Four persons referred for work hardening at the University of Pittsburgh Medical Center were recruited for the study. Each participant gave written informed consent, approved by the University of Pittsburgh Biomedical Institutional Review Board. The study criterion was a diagnosis of persistent back pain in the lumbar region (up to the first lumbar vertebrae) of 3 months duration or longer. Persons with a history of cancer, systemic disease, disabling comorbidity, major cardiovascular disease by history, pregnancy, significant lumbar stenosis, or major psychiatric conditions were excluded. Table 1 presents participants’ demographics.

Procedure

Treatment protocol. The work-hardening program was structured for 2 hr per day the first week and then increased in weekly increments to 3, 4, 5, and finally, 6 hr per day as the participant’s strength and endurance developed. Treatment averaged 8 weeks in duration, although Participant 4 received only 5 weeks. The treatment program continued as long as progress was made and, ultimately, until long-term goals were met. The treatment program included physical reconditioning, job task simulation, and body mechanics instruction (BMI). The instructional portion of the program was divided into didactic and demonstration sessions. The didactic sessions covered spinal anatomy, biomechanics of the spine, and task analysis. The use of lecture protocols and associated visual aids promoted continuity among the four treating therapists. The demonstration sessions were designed to instruct the participant in the application of body mechanic principles. The primary principles emphasized were: maintain spinal alignment, keep the object close to the center of gravity, face the object to avoid twisting, use both sides of the body equally, and maintain a wide base of support. Application was reinforced during the job simulation and physical reconditioning tasks on a daily basis. The amount of cues needed to correct a participant’s technique per observation was recorded daily by the treating therapist.
Table 1 Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Work-Hardening Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (gender)</td>
<td>1</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>2</td>
</tr>
<tr>
<td>Time since onset to admission</td>
<td>3</td>
</tr>
<tr>
<td>Occupation</td>
<td>4</td>
</tr>
<tr>
<td>Length of employment</td>
<td>1.5 years</td>
</tr>
<tr>
<td>Physical demand class of the job</td>
<td>Medium-heavy</td>
</tr>
<tr>
<td>Physical demand class at admission(^a)</td>
<td>Part-time medium</td>
</tr>
<tr>
<td>Return-to-work status</td>
<td>Full duty</td>
</tr>
</tbody>
</table>


on an assessment form. The amount, expressed as a percentage, was calculated by the experimenter as a ratio of the total number of observations requiring cues to the total number of observations for the week.

**Lifting protocol.** The testing protocol included the static and isodynamic lifting portions of the functional capacity evaluation standardized by Rudy, Lieber, and Turk (1991). This protocol was chosen because it has been shown to be sensitive to treatment effects and was able to discriminate between healthy persons and persons with chronic back pain who had participated in an interdisciplinary pain rehabilitation program (Boston, Rudy, Lieber, & Stacey, 1995). The static strength portion consists of a bilateral symmetrical leg lift at knee level, which is measured with a Muscle Strength Dynamometer\(^1\) and the average of three trials. The isodynamic endurance portion of the protocol uses the BTE Work Simulator\(^2\) with its force adjusted to 40% of the mean weight of the three static lifts. The participant lifts the 12-in. handle from a holder located 13 in. above the floor up to waist level and then returns the handle to the holder. The simulator applies constant resistance during the lift and no resistance as the handle is being returned to the holder. The lifting interval was set at 15 sec, and participants were instructed to return to a standing position between lifts. Participants were instructed to continue the lift task until they were physically unable to continue or were told by the examiner to stop. Testing was terminated if the participant demonstrated unsafe or unstable movements or if the 20-min time limit was reached. Throughout, no visual or verbal feedback was given to the participant regarding his or her performance.

Body movements used during the lifting protocol were recorded with a video processor and analyzed with Expert Vision software from Motion Analysis\(^3\). Infrared reflectors were placed on the participant’s left side using four anatomical landmarks. Two hemispheric reflectors were attached, one at the top edge of the acromion process and the other centered on the greater trochanter of the femur. Two band reflectors were wrapped around the leg, one at the apex of the patella and the other superior to the lateral malleolus of the fibula. These sites were selected to allow freedom of movement, maximum reliability of placement, and the best definition of the body movements of interest, that is, hip and knee angles (Chaffin & Andersson, 1991). These markers were used to define the shoulder, hip, knee, and ankle in two dimensions.

**Measures**

**Global performance measures.** Three indexes were used to evaluate changes after treatment: static lift strength; the number of dynamic lifts (endurance) completed; and a modified index of work, defined as the amount of weight lifted times the number of lifts completed.

**Body mechanic measures.** Motion analysis data obtained during the up-phase of the repetitive lifting was analyzed because resistance was applied only during that phase of the task. Three channels from the BTE Work Simulator (force, rotational speed of the exercise head, rotational direction) were used to determine the start and end times of the up-phase. Expert Vision software was used to calculate the x-y coordinates of the centroid of each reflective marker for the frames acquired during the up-phase of a lift. The location of each marker was identified in the first frame and then tracked during the lift to define the trajectories of the shoulder, hip, knee, and ankle in two dimensions. The hip angle, defined by the shoulder–hip–knee markers, and the knee angle, defined by the hip–knee–ankle markers, were calculated for each frame. The lifting motion was described by these two body angles, which were computed in terms of degrees of flexion from an upright stance. Changes in these angles during the lift defined functions of time, as illustrated for a typical lift in Figure 1. Separate hip and knee angle time functions were computed separately for each lift for each participant.

As displayed in Figure 1, the angle time functions have a sigmoidal shape. This shape has been represented accurately by the hyperbolic tangent function, which contains...
the following four parameters:

1. The initial (maximum) angle
2. The final (minimum) angle
3. The temporal midpoint, which was the time after
   the beginning of the lift when the angle had com-
   pleted onehalf of its range of movement
4. The falltime, defined by this function as the time
   required for the angles to decrease from 12% to
   88% of the total decrease in the angles

These parameters provided a mechanism to compare angle data across repetitive lifts (Boston et al., 1993). They
were treated as a correlated set of time series in which the
sampling frequency was equal to the rate at which lifts were
performed. The beginning and ending lift angles were used
to calculate the total range of motion of the body angle
during the up-phase of the lift. The midpoint was used to
define the time after the beginning of the lift when the hip
or knee angle had completed one half of its range of
motion. The falltime reflected the speed of the lift. The
hyperbolic tangent function is displayed in Figure 2. To
eliminate the effects of changing lift durations, for each lift
the hip and knee midpoints were normalized by the total
duration of the lift. The midpoint normalized by the total
duration of the lift estimated the proportion of the total lift
time required for the body angle to complete one half of its
total range of movement. Thus, if the speed of lifting in-
creased or decreased over repetitive lifts but the relative
movement of the hip or knee remained constant within each
lift, the normalized midpoint remained constant over time.
For similar reasons, falltimes were normalized by the total lift
duration and were used to represent the proportion of the lift
duration over which most joint motion had occurred.

Differences between hip and knee starting angles also
were computed for each lift (hip minus knee). Positive dif-
ferences greater than 60º indicated a more torso-starting
style, differences between 0º and 55º indicated a leg lift,
and negative differences were indicative of a squat lift.
Similarly, to evaluate the dynamic, temporal synchronism
of these two joints during each lift, the difference between
the hip and knee midpoints was computed. A zero differ-

![Figure 1. Typical hip and knee angle changes over time during the up-phase of a single lift.](image)

Figure 1. Typical hip and knee angle changes over time during the up-phase of a single lift.

![Figure 2. Diagram of the hyperbolic tangent function used to describe changes in hip and knee angles during a lift.](image)

Figure 2. Diagram of the hyperbolic tangent function used to describe changes in hip and knee angles during a lift.

ence between the temporal midpoints indicated that the
two angles reached their midpoints at the same time, that
is, their motion was synchronous. If the difference was
non-zero, this indicated that one joint angle reached its
halfway point before the other, which was representative of
asynchronous motion between the hip and knee during the
lift. Finally, the absolute (unnormalized) duration of each
lift in seconds was derived from output from the BTE
Work Simulator. Lift duration data, like body motion data,
were used to determine the effects of treatment as well as
the effects of prolonged repetitive lifting.

Data Analysis

Treatment effects for the overall performance-dependent mea-
sures were evaluated separately for each participant. An effect
size was computed between pretest and posttest treatment
scores for each participant by dividing the differences between
two means by the pooled standard deviations. Lipsey’s (1990)
guidelines suggested that values between .30 and .50 are mod-
est treatment effects; values between .50 and .80 are moder-
ate; and values greater than .80 are considered major. For compar-
ison purposes, particularly to compute treatment effect sizes
and to determine the degree to which the participants
approached normal performance following treatment, sum-
mary data from Boston et al. (1995) were used. This study
consisted of 52 control participants and 52 patients with
chronic low back pain who participated in a comprehensive
pain management program (this program did not include a
work-hardening component, as in the present study) and who
completed the same lifting protocol.

To test changes in body mechanics, a 2-within com-
pletely crossed experimental design was used. The first
within or repeated factor was the time of assessment (pre-
treatment vs. posttreatment), and the second was the time
during the dynamic task or phase (early, middle, late).
Hyperbolic tangent and lift duration parameters were com-
pared for each lift for each participant and then averaged to
obtain estimates of these parameters for the beginning, the
middle, and the end of the sequence of repetitive lifts. Each
estimate was the mean value obtained from five consecutive
lifts (first 5, middle 5, last 5). This averaging process simpli-
fied data analyses, provided more reliable or stable parame-

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Table 2
Static Strength at Pretest and Posttest

<table>
<thead>
<tr>
<th>Time and Measure</th>
<th>Work-Hardening Participant</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Static lift (lbs)</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Pretest</td>
<td>63.33</td>
<td>12.58</td>
<td>80.00</td>
<td>17.32</td>
</tr>
<tr>
<td>Posttest</td>
<td>123.33</td>
<td>57.74</td>
<td>240.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Pre–Post Static Lift</td>
<td>Effect size</td>
<td>1.36</td>
<td>4.05</td>
<td>6.06</td>
</tr>
</tbody>
</table>

Table 3
Participants’ Posttreatment Performances Compared to Control Participants

<table>
<thead>
<tr>
<th>Measure</th>
<th>Work-Hardening Participant</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Control Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean static lift (lbs)</td>
<td>80</td>
<td>105</td>
<td>115</td>
<td>240</td>
<td>222.1</td>
<td>104.5</td>
</tr>
<tr>
<td>Number of lifts</td>
<td>69</td>
<td>32</td>
<td>60</td>
<td>49</td>
<td>(194.2–249.8)</td>
<td>(91.1–118.0)</td>
</tr>
<tr>
<td>Work index</td>
<td>2208</td>
<td>1344</td>
<td>2760</td>
<td>4704</td>
<td>68.4</td>
<td>68.1</td>
</tr>
<tr>
<td>Mean lift duration (sec)</td>
<td>1.45</td>
<td>1.81</td>
<td>2.25</td>
<td>1.74</td>
<td>(65.4–71.5)</td>
<td>(64.3–71.9)</td>
</tr>
<tr>
<td>Mean starting posture (hip–knee flexion)</td>
<td>–42.78</td>
<td>29.80</td>
<td>–1.33</td>
<td>53.38</td>
<td>5965.0</td>
<td>2870.2</td>
</tr>
<tr>
<td>Mean hip–knee temporal midpoints</td>
<td>–0.006</td>
<td>–0.018</td>
<td>–0.012</td>
<td>0.108</td>
<td>(5382.7–6747.3)</td>
<td>(2463.8–3276.6)</td>
</tr>
</tbody>
</table>

Note: n = 24 for male control participants; n = 28 for female control participants.

Participants 1 and 4 are men participants; 2 and 3 are women. Numbers in parentheses represent the 95% confidence interval of the mean.

Results

Global Performance Measures

Table 2 displays the mean and standard deviations for the three static strength trials conducted pretest and posttest. With the criterion of > .80 for major effect sizes, findings indicate major increases in static lifting strength after treatment for all 4 participants when compared with the control group. Static strength values were not significantly different; only Participant 4 (male) displayed strength equivalent to those for male control participants (see Table 3).

As Table 4 reveals, both the number of lifts completed and the amount of work performed increased for all participants following treatment. Based on pretreatment standard deviations of the work indexes for 52 patients with chronic low-back pain (Boston et al., 1995), computed separately by gender, Participants 2, 3, and 4 displayed major treatment effect sizes, and the effect size for Participant 1 was modest.

The number of dynamic lifts completed by Participants 1 and 3 were not significantly different than those completed by control participants (Table 3). However, they were significantly less for Participants 2 and 4. Comparison of the work indexes to same gender control groups indicated that only Participant 3 had a posttreatment work index that was not significantly less than that produced by the control participants.

Body Mechanics Measures

The hip and knee angles during the up-phase of the lift were described well as functions of time by the hyperbolic tangent model. The mean goodness-of-fit ($R^2$) value across all participants and all lifts was .996 for the hip angle ($SD = .003$) and .993 for the knee angle ($SD = .005$). These results indicate that the four parameters of the hyperbolic tangent function (starting angle, ending angle, midpoint, falltime) provided an accurate data reduction summary of the primary components of the more complex hip and knee angle time series that occurred during each lift. Additionally, MANOVAs for the hip and knee $R^2$ values indicated no significant differences for time of testing (pretreatment vs. posttreatment), for task phase (early, middle, late), and across participants.

Participant 1. The means, standard deviations, and the results of the MANOVAs for the three body mechanics measures (lift duration, starting posture, hip–knee temporal midpoints), for Participant 1 are displayed in Table 5. These results indicate (a) a significant decrease in lift duration (pre-$M = 2.44$ sec, post-$M = 1.47$ sec); (b) a significant change in lift duration across the early, middle, and late phases of the task; (c) a significant change in lifting posture to a deeper squat at posttest (hip–knee flexion pre-$M = –8.72$, post-
**Table 4**

**Dynamic Lifting Task, Overall Performance Indexes**

<table>
<thead>
<tr>
<th>Time and Measure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of lifts</td>
<td>64</td>
<td>15</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Work index</td>
<td>1600</td>
<td>300</td>
<td>350</td>
<td>1372</td>
</tr>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of lifts</td>
<td>69</td>
<td>32</td>
<td>60</td>
<td>49</td>
</tr>
<tr>
<td>Work index</td>
<td>2208</td>
<td>1344</td>
<td>2760</td>
<td>4704</td>
</tr>
<tr>
<td>Pre–Post work Index</td>
<td>0.43</td>
<td>1.94</td>
<td>4.47</td>
<td>2.37</td>
</tr>
</tbody>
</table>

$M = -41.46$; (d) a significant time of testing by task phase interaction for starting posture; and (e) no significant changes in dynamic measures of body mechanics (i.e., hip–knee midpoints) for time of testing or task phase.

Post hoc contrasts, computed to interpret further the significant task phase main effect, indicated that lift duration decreased significantly between the middle and late phases of the task, $F(1,4) = 21.84$, $p < .01$, but not between the early and middle phases, $F(1,4) = .67$, $p = ns$. Calculation of simple main effects indicated that Participant 1’s starting lifting posture changed significantly during the pretreatment testing from a leg-style to a squat-style lift later in the task, $F(2,3) = 280.01$, $p < .001$. However, the initial squat-style lifting posture did not change significantly during the posttreatment testing, $F(2,3) = 9.61$, $p = ns$.

**Participant 2.** Dynamic lifting parameters for Participant 2 are displayed in Table 5. These results indicated (a) a significant decrease in lift duration posttest (pre-$M = 2.55$ sec, post-$M = 1.93$ sec); (b) a significant change in starting lifting posture from a torso-style lift at the pretreatment testing to a leg-style starting posture at posttreatment (hip-knee flexion pre-$M = 57.16$, post-$M = 24.45$); (c) a significant interaction in time of testing by task phase for starting posture; and (d) no significant difference in hip–knee synchronization measures across time of testing or task phases. Simple main effects indicated that Participant 2’s starting lifting posture changed significantly during the pretreatment testing from the early to the middle phases of the task, $F(1,4) = 21.86$, $p < .01$, but no significant changes in starting posture occurred at posttesting, $F(2,3) = .99$, $p = ns$.

**Participant 3.** Dynamic lifting parameters for Participant 3 are displayed in Table 5. These results indicated (a) a significant decrease in lift duration at the time of the posttest (pre-$M = 4.26$ sec, post-$M = 2.32$ sec); (b) a significant change in lift duration and starting posture across task phases; (c) a significant interaction in time of testing by task phase for starting posture; and (d) no significant difference in hip–knee synchronization measures across time of testing or task phases.

Post hoc contrasts indicated that lift duration decreased significantly between the early and middle phases of the task, $F(1,4) = 43.38$, $p = .01$, but not between the middle and late phases, $F(1,4) = 1.84$, $p = ns$. The significant interaction between time of testing and task phase for starting posture is plotted in Figure 3. Simple main effects

**Table 5**

**Measures of Body Mechanics by Participant, Time of Testing, and Task Phase**

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pretest</th>
<th>Posttest</th>
<th>$F$ tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early</td>
<td>Middle</td>
<td>Late</td>
</tr>
<tr>
<td>Participant 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift duration (sec)</td>
<td>2.56</td>
<td>2.47</td>
<td>2.27</td>
</tr>
<tr>
<td>(0.36)</td>
<td>(0.53)</td>
<td>(0.19)</td>
<td>(0.30)</td>
</tr>
<tr>
<td>Starting posture</td>
<td>15.78</td>
<td>-5.73</td>
<td>-36.20</td>
</tr>
<tr>
<td>(hip–knee flexion)</td>
<td>(5.45)</td>
<td>(9.36)</td>
<td>(1.29)</td>
</tr>
<tr>
<td>Hip–knee temporal midpoints</td>
<td>-0.04</td>
<td>0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>(0.02)</td>
<td>(0.04)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>Participant 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift duration (sec)</td>
<td>3.07</td>
<td>2.31</td>
<td>2.31</td>
</tr>
<tr>
<td>(0.99)</td>
<td>(0.15)</td>
<td>(0.19)</td>
<td>(0.28)</td>
</tr>
<tr>
<td>Starting posture</td>
<td>50.87</td>
<td>60.39</td>
<td>60.23</td>
</tr>
<tr>
<td>(hip–knee flexion)</td>
<td>(5.44)</td>
<td>(2.97)</td>
<td>(3.95)</td>
</tr>
<tr>
<td>Hip–knee temporal midpoints</td>
<td>0.01</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>(0.02)</td>
<td>(0.03)</td>
<td>(0.04)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Participant 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift duration (sec)</td>
<td>4.97</td>
<td>3.85</td>
<td>3.96</td>
</tr>
<tr>
<td>(0.38)</td>
<td>(0.20)</td>
<td>(0.21)</td>
<td>(0.25)</td>
</tr>
<tr>
<td>Starting posture</td>
<td>16.06</td>
<td>3.10</td>
<td>-7.23</td>
</tr>
<tr>
<td>(hip–knee flexion)</td>
<td>(4.59)</td>
<td>(1.97)</td>
<td>(5.05)</td>
</tr>
<tr>
<td>Hip–knee temporal midpoints</td>
<td>-0.03</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.02)</td>
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<tr>
<td>Participant 4</td>
<td></td>
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</tr>
<tr>
<td>Lift duration (sec)</td>
<td>2.71</td>
<td>3.07</td>
<td>4.11</td>
</tr>
<tr>
<td>(0.18)</td>
<td>(0.04)</td>
<td>(0.31)</td>
<td>(0.34)</td>
</tr>
<tr>
<td>Starting posture</td>
<td>23.34</td>
<td>68.12</td>
<td>76.85</td>
</tr>
<tr>
<td>(hip–knee flexion)</td>
<td>(5.10)</td>
<td>(10.88)</td>
<td>(4.56)</td>
</tr>
<tr>
<td>Hip–knee temporal midpoints</td>
<td>0.02</td>
<td>-0.02</td>
<td>-0.11</td>
</tr>
<tr>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.02)</td>
<td>(0.02)</td>
</tr>
</tbody>
</table>

*Degrees of freedom for Time main effect $F$ tests are 1,4. *Degrees of freedom for Phase main effect $F$ tests are 2,3. *Degrees of freedom for Time by Phase interaction $F$ tests are 2,3. *Numbers in parentheses are standard deviations.
indicate that Participant 3’s starting lifting posture during the pretest changed significantly between the early and middle phases, $F(1,4) = 25.48, p = .01$ and between the middle and late phases, $F(1,4) = 16.91, p < .01$, from a leg-style to a squat-style lift. However, initial lifting posture at the time of the posttesting changed significantly from a leg-style to a squat-style lift between the early and middle task phases, $F(1,4) = 33.76, p < .01$, and then remained unchanged for the rest of the task.

**Participant 4.** Dynamic lifting parameters for Participant 4 are displayed in Table 5. These results indicated (a) a significant decrease in lift duration at the posttest ($pre-M = 3.30$ sec, $post-M = 1.80$ sec); (b) significant change in starting posture from leg to torso lift across the task phases at pretest; (c) significant increase in hip–knee temporal midpoints at the time of the posttest ($pre-M = -.039$, $post-M = .102$), which indicates that at pretest the hip led the knee during lifting, but at posttest this was reversed with the knee leading the hip; and (d) a significant interaction in time of testing by task phase for lift duration, starting posture, and hip–knee midpoints.

Simple main effects indicated that Participant 4’s pretest lifting duration increased significantly between the middle and late task phases, $F(1,4) = 16.94, p = .01$, but decreased at posttest between the middle and late task phases, $F(1,4) = 21.86, p < .01$. Lift duration between the early and middle task phases for the pretest and posttest were not different statistically.

Figure 4 plots the significant time of testing by task phase interaction for starting lifting posture. Simple effects indicated no significant differences across task phases for starting posture at the posttreatment assessment. However, at pretreatment, starting lift posture increased significantly from a leg-style to a torso-style lift from the early to the middle task phase, $F(1,4) = 141.70, p < .001$, but the change in starting posture was not significant between the middle and late phases, $F(1,4) = 2.16, p = ns$.

Finally, for Participant 4, the significant time by phase interaction for hip–knee midpoints is plotted in Figure 5. Simple main effects indicated no significant differences among task phases for hip–knee midpoints at the time of the pretreatment testing, $F(2,3) = 4.22, p = ns$. Post hoc contrasts indicated hip–knee midpoint scores were significantly less at posttest than at pretest middle task phase hip–knee midpoints, $F(1,4) = 115.81, p < .001$, as were late task phase values, $F(1,4) = 23.78, p < .01$. In sum, the dynamic movement strategies used by this participant were fundamentally different between pretest and posttest.

**Treatment effect sizes for body mechanics measures.** Overall treatment effect sizes for each participant and each of the three body mechanics–dependent measures were computed by pooling across the means and standard deviations for the three task phases separately for the pretreatment and posttreatment tests. Effect sizes then were computed by taking the absolute difference of the pretreatment and posttreatment means and dividing this difference by a pooled pretreatment–posttreatment estimate of variance for each measure. These results are presented in Table 6. Only lift duration displayed a major treatment effect ($> .80$) for all 4 participants. Two participants (Participants 1 and 2) displayed major effect sizes for starting lifting posture, and only Participant 4 displayed a major treatment effect size for hip–knee synchronization. All participants displayed major effect sizes when the mean effect size was computed for the three measures of body mechanics.

**Posttreatment body mechanics measures compared to control participants.** The measures of body mechanics for each participant at the time of the posttest were compared to those obtained from 52 control participants. The lift dura-
tion of Participants 2, 3, and 4 remained significantly slower than the lift duration found for control participants (see Table 3). Additionally, Participants 1 and 3 performed more of a squat lift than that observed for control participants, the starting posture for Participant 2 approached the leg-style lifting observed for female control participants, and Participant 4 displayed significantly greater torso flexion at the start of the lift compared to the male control participants. Finally, the hip–knee movement synchronization during the lift was not significantly different than that found for control participants for Participants 1, 2, and 3. However, Participant 4 displayed significantly different hip–knee motion or coordination patterns, that is, more uncoordinated movement than found for control participants and the other three work-hardening patients included in this study.

### Discussion

The clinically significant treatment effects detected for static strength, number of lifts, and the global work index were attributed to the physical reconditioning that occurred as the result of work hardening. Similar changes in strength have been reported following this type of treatment program by Robert, Blide, McWhorter, and Coursey (1995). However, the dynamic measures did not approximate as closely to the control participants as seen in the static strength. We theorize that this could be the result of adherence to the teaching concept of pacing for symptom management or perhaps the greater energy expenditure required to perform the squat-style lift (Hagen, Hallen, & Harms-Ringdahl, 1993).

The motion analysis and BTE output data revealed that lift duration was the only variable affected significantly by treatment for all participants. The decrease in lift duration, that is, the increase in lifting speed, also is considered a by-product of the reconditioning and may have been due to a decrease in fear of lifting, although not measured directly in this study. Crombez, Vervaet, Lysens, Baeyens, and Eelen (1998) have proposed that there is an inverse relationship between fear and performance. A review of the literature on the effects of lifting speed raises doubts about whether striving to normalize lifting speed would be an appropriate focus of treatment (Hsiang, Brogmus, & Courtney, 1997). For example, based on the studies of Buseck, Schipplein, Andersson, and Andriacchi (1988) and Bush-Joseph, Schipplein, Andersson, and Andriacchi (1988), the decrease in lift duration suggests that the participants produce a greater moment at L5-S1. Specifically, Bush-Joseph et al. found that the peak moment increased proportionately with increased lift speed and that the increase was greatest in back (torso) lifts. Buseck et al. also reported a linear relationship between the peak moment at L5-S1 and the speed of the lift. Additionally, they found that the moments were lower during a leg lift than a free-style lift. Thus, starting posture is an integral component to examine when postulating the moment produced at L5-S1 during lifting.

Three of the four participants demonstrated changes in starting posture consistent with the body mechanics instruction provided during treatment. That is, they shifted more of the workload to their legs to reduce the load on the lumbosacral junction. Compared to the gender-matched control participants, two participants performed more of a squat lift than observed and one participant displayed significantly greater torso flexion. Thus, only one participant demonstrated a leg-style lift that was similar to the control participants. The trend to perform a squat lift may be attributed to more than simple adherence to instruction. For example, the decrease in the moment at L5-S1 when performing a leg lift, detected by Buseck et al. (1988), may lead to reduced nociceptive input. Additionally, the weakness in trunk extensor detected in earlier studies conducted by Holmstrom, Mortiz, and Andersson (1992); Reid, Hazard, and Fenwick (1991); and Smith, Mayer, Gatchel, and Baker (1985) also may contribute to the tendency of most participants to perform a squat lift.

According to the discharge reports, each participant met the goal of demonstrating independence in the use of proper body mechanics. A comparison of the goal attainment with the percentage of cues given to reinforce the application of body mechanics principles during the final week of treatment revealed agreement for Participants 2, 3, and 4 but not Participant 1. This participant consciously reverted back to demonstrating pretreatment patient transfer methods in anticipation of needing to conform to the practices of his coworkers, as reported by the participant to the treating therapist.

The changes detected by the motion analysis data reveal complexities involved in performing a functional task that are unlikely to be discernable by simple observation methods. For example, the significant interaction between time of testing and task phase demonstrated by all four participants’ starting posture illustrates the variability that can exist during repetitive lifting. In addition, the coordination or synchrony between the hip and knee joints unveiled by the motion data deepens our understanding of the act of repetitive lifting. Similar findings have been noted by Scholz and McMillan (1995) and Scholz, Milford, and McMillan (1995), who examined the effect of increasing load on the coordination of the hip and knee joints in asymptomatic participants. The synchrony
demonstrated by three of the four participants was not significantly different than that found for control participants. This is in contrast to Boston et al. (1993), who found less synchrony in patients with chronic back pain than in healthy controls. Perhaps the shorter duration of disabling back pain ($M = 6.8$ months off work) in the participants of this study versus the 4.1 year duration in the Boston et al. (1995) study could explain why our participants had not adopted the dysfunctional movement patterns found in persons with chronic low back pain of greater duration.

**Limitations**

The assessment protocol used in this study included a standardized isodynamic lifting protocol (Rudy et al., 1991) and measurement instruments (e.g., motion analysis, work simulator) that have been proven to be reliable and valid in detecting treatment effects as well as differences between persons with and without chronic back pain (Boston et al., 1993, 1995). Nevertheless, several limitations exist with this technology. First, the lifting protocol was restricted to measuring only the endurance for lifting and under load because the BTE Work Simulator used in this study cannot apply resistance during the lowering phase of the lift. Second, the body motion recorded was designed to detect changes in gross body angles and was unable to identify changes in spinal alignment, such as the presence or absence of lordosis. Third, the study did not use biomechanical modeling to estimate joint forces and moments. Finally, the small sample restricts the generalizability of these results.

**Conclusion**

This study revealed that intensive BMI that occurred during work hardening had a significant effect on the global performance indexes of static strength, dynamic endurance, and work for the 4 study participants. The use of the motion analysis also revealed a significant effect on the body mechanic measures of starting posture and lifting speed for 3 participants. These changes may be attributed to the feedback from the therapists regarding lifting technique and the effects of physical reconditioning inherent in the treatment process. The presence of synchrony between the hip and knee joints for 3 participants and the persistence of asynchrony in 1 participant confirm the assertions made by Scholz (1992) that different coordination patterns might diverge from the same initial lifting posture or may differ across persons performing in the same situation. In addition, this study revealed that coordination patterns can vary within the participant and within a sustained dynamic task. Burgess-Limerick, Abernathy, and Neal’s (1995) study on interjoint coordination during repetitive lifting reaffirms that an adequate description of lifting technique or body mechanics requires consideration of both the starting posture and the interjoint coordination. Thus, the clinician must realize that measuring the effects of BMI is multidimensional and far more complex than adherence to basic guidelines that can be captured in an observation checklist. Additionally, it is possible that the body mechanics training administered in the clinical setting may not be deemed ecologically valid in the workplace or that a person may adopt a lifting style to perform work duties that becomes the technique he or she uses for all lifting situations.

This study raises questions for further research. Does the educational set used in training have an impact on the use of body mechanics principles? Does the intensity of instruction influence the degree of behavior change? Does the manner in which patients receive feedback (verbal vs. video vs. motion analysis) influence the desired outcome? Can coordination of the hip and knee joints be directly influenced by instruction? Can a person modify his or her lifting style to perform lifting in a variety of situations? Additional, carefully controlled studies, particularly in more work-related settings, are necessary to address these issues.

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