Mechanical and Electromyographic Comparison Between the Stoop and the Squat Lifting Methods

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In an attempt to explain why humans typically lift light objects using the stoop lifting method, as opposed to the recommended squat lifting method, a biomechanical and an electromyographic analysis of both the stoop lift and the squat lift was performed in which the following variables were compared: the peak moment about the knee, the peak EMG activity of the knee extensors, the total mechanical work, and the duration of each lift. Eight subjects were filmed, each using both methods to lift small objects of 2.27, 4.54, and 6.81 kilograms. The mean and standard deviation of these variables for each object were calculated for each lifting method. A discriminant analysis with a stepwise selection was then applied to the these variables to determine which of these variables maximally distinguishes the stoop from the squat lifting method. In addition, a 2 x 3-repeated-measure analysis of variance (ANOVA) was applied to the values representing the peak moment about the knee, the peak EMG activity of the quadriceps muscle, the total mechanical work, and the duration of each lift.

The discriminant analysis revealed that, among the investigated variables, the moment about the knee was the variable which maximally distinguished the two lifting methods. It was therefore concluded that humans may naturally prefer the stoop lifting method to the squat lifting method because of the greater demand the squat lift imposes on the knee extensors. The results suggest that the relatively greater mechanical work required to perform the recommended squat lift is also an important factor in explaining why humans naturally prefer the stoop lifting method. These conclusions are limited to the lifting of small objects weighing 6.81 kilogram or less.
lower back creates a great mechanical load. This is demonstrated by the large moment about the lower back — a result of the high value of the product of the weight of the upper body and its lever arm. The axis of movement in flexion and extension of the spine in lifting objects passes through the nucleus pulposus of the intervertebral discs (Fick, 1904). Not surprisingly, this is the site of the most serious lower back injuries (Chaffin, 1969). The lever arm of the lower back muscles in this area is very short, approximately as big as the diameter of these vertebrae (Chaffin & Andersson, 1984). Therefore, because of this mechanical disadvantage, the lower back muscles have to create a tremendous amount of force to resist the combined load of the upper body and the lifted object when bending forward.

Ekholm, Arborelius and Nemeth (1982) reported that lifting with straight knees gives a moment force of 217 Newton-meters (Nm) at the beginning of the lift and a compressive force of 4390 Newtons (N) at the L5-S1 disc. Also, Wood and Hayes (1976) found that in a simple lifting motion the intervertebral force, acting about the L4 and L5, has a maximum value of over 3924 N during the initial phase of the lift. Andersson, Ortengren and Nachemson (1976) found that the mean peak disc pressure on the third lumbar disc during dynamic lifting was 1.50 (SD = +0.05) kilo-Pascal (kPa) in the “leg lifting method” as opposed to 1.83 (SD = +0.13) kPa in the “back lifting method.” Roozbazar (1974) found that the compressive force on the disc in a stooped position is 5140.4 N when the role of the abdominal pressure is considered. Because the erector spinae muscle in this position is inactive (MacConaill & Basmajian, 1969), this load is supported by the ligaments and other organs of the back. Therefore, the danger of torn ligaments is much greater.

Grieve (1974) compared some dynamic characteristics of the squat and the stoop lifting methods. The subjects lifted loads, fitted with a horizontal rod handle, located 29 cm above a platform, onto a shelf positioned either 61 or 78 cm above the platform. The subjects stood on a Whitney Force Platform and the load (4, 14, or 29 kg) rested initially on a force transducer. An accelerometer was attached to the load. Galvanometer measurements were taken of the forces at the feet and on the load support, as well as of the acceleration of the load.

Grieve (1974) reported that the rates of work (the product of force and velocity) of the Whitney Force Platform and the accelerometer were computed throughout each lift. The findings emphasized the great differences in the use of the devices for the two methods of lifting. The force platform produced a much greater power output during the squat lifts than it did during the stoop lifts. The accelerometer absorbed energy shortly before and after lift-off during the squat lift, eventually producing a little more than it had absorbed by the later stage of the lift. By contrast, during the stoop lift, the platform and the accelerometer achieved similar rates of power output.

Roozbazar (1974) investigated the effect of compressive stress, shear stress, and bending moment on the intervertebral disc, between L5 and S1, during three methods of lifting. The results showed the superiority of the back erect/knees bent method over the inclined back/bent knees and the back vertical/bent knees methods. It was argued that this superiority rests upon the fact that the back vertical/bent knees method causes significantly less moment, compressive stress, and tangential stress on the annulus fibrosus. Thus, Roozbazar concluded that the maximal weight as set by the International Labor Office for male industrial workers can be lifted most efficiently with a vertical back and bent knees.

Carpenter (1938) studied the movement in which 26 subjects produced their maximum upward pull on a bar that was attached to a hip belt. A chain linked the bar to a dynamometer on the floor. The optimum posture was one involving 56–65 degrees of knee flexion. There was a dramatic decrease in performance in Carpenter’s experiments as the knee was further flexed. This may provide a key to the Davis and Troup (1964) observations that squat lifts tend to convert to stoop lifts after they begin. Such a transition has the effect of stretching the hamstring muscles, which may more than compensate for the additional demand for torque at the hip that is imposed by the stoop lifting method.
Waters, Perry, McDaniels, & House (1974) measured maximal extensor torques at the hip for eight women aged 19–27 years at 0, 15, 45, and 90 degrees of flexion of the hip, with knees extended and 90 degrees flexed. Their results suggested that the hip extensors may be 2.5 times stronger in a stoop lift commenced from the ground than they are in a stoop lift commenced from an erect posture.

Giat (1984) found that the squat lifting method requires more mechanical work than that required to perform the stoop lift. This is an important factor in explaining why people select the stoop as opposed to the squat lifting method.

The purpose of this study was to investigate what causes people to use a procedure that may be harmful to their lower back. In particular, it was intended to investigate the following factors in distinguishing the stoop and the squat lifting methods: the peak moment about the knee due to the weight of the upper body, the thighs, and the lifted object; the peak EMG activity of the knee extensors; the total mechanical work; and the duration of each lift.

This investigation was limited to the lifting of light objects in order to preserve the freedom of choice that the subject has between the stoop and the squat lifting methods; the relative ease with which light objects can be lifted tends to maximize this freedom of choice. As the weight of the lifted object increases, so does the need both to maintain the stability of the upper body and to generate greater effort. The relatively greater degree of exertion required may cause other mechanical events, which are not the subject of this investigation, to dictate the use of either one or the other lifting method or some combination of the two. Therefore, only light objects were used in an effort to explore more precisely the mechanical events that motivate the choice of a particular lifting method.

The importance of this study can be described as follows: lower back pain is one of the most common causes of illness and affects between 50% and 80% of the population (Hult, 1954; Nachemson, 1971; Chaffin & Park, 1973; Chaffin, 1975; Andersson, 1976). The back, specifically the lower lumbar segments of the spinal column, is one of the body parts most highly stressed during lifting (Chaffin & Andersson, 1984). As Armstrong (1965) pointed out, the spine is biomechanically a “weak link” in the human musculoskeletal structure. Furthermore, approximately 90% of all serious back injuries, for example disc herniation, occur at the two lower lumbar discs (Armstrong, 1965; Smith, Deery, & Hagman, 1944). Investigation of the mechanical characteristics, the movement of the lower back, and the knee helps one to understand this problem.

METHODS

Eight male volunteers between 18 and 24 years of age were the subjects for this investigation. Their average height was 1.73 meters and their average weight was 74.37 kilograms.

The Biomechanical Model

A co-planar, five-links, quasi-static model was considered in this investigation. This model, depicted in Figure 1, represents the major segments as follows: Let B₁,...,B₅ represent the shank, the thigh, the trunk, the upper extremity, and the lifted object, respectively; and let Bᵢ* indicate the mass center location of Bᵢ (i = 1,...,5); also let P₁,...,P₄ represent the joint centers of the ankle, the knee, the hip, and the shoulder. The mutually perpendicular and dextral unit vector basis {n₁, n₂, n₃} is fixed in the filming environment where n₁ indicates the direction of the gravitational forces of the earth. The moment, M, that the weight of the body segments and the lifted object produce about the knee was computed as

\[ M = \sum_{i=2}^{5} r_i \times (m_i g n_1) \cdot n_3 = -g n_2 \cdot \sum_{i=2}^{5} r_i m_i \] (1)

where \( r_i \) is the position vector from P₂ to Bᵢ*, \( m_i \) indicates the mass of segment i and g indicates...
FIGURE 1
BIOMECHANICAL MODEL OF THE BODY SEGMENTS AND LIFTED OBJECT

\[ \text{WORK} = \sum_{i=1}^{5} m_i h_i \]

where \( h_i \) indicates the vertical distance that \( B^*_i \) travels throughout the lifting phase of the movement. The total mechanical work was assumed to include only the potential energy, not any kinetic energy, since the subjects began and completed the lifting phase from rest positions (Kane & Levinson, 1985).

Experimental procedures. Three black metal discs of 19 cm in diameter and 2.5 cm in thickness were used as the objects to be lifted. The three identical discs weighed 2.27 kg each. The object was placed on a wooden block of 10 x 5 x 5 cm, which was located in the plane of motion, so that the subject could easily grab it.

The subjects were weighed prior to filming and were each given an identification number. The ankle, the knee, the hip, the shoulder, the elbow, the wrist, the center of gravity of the hand, and the top of the head were marked on each subject’s right lateral side. The subjects were instructed to lift the object naturally according to the following instructions: (a) Walk toward the object and stand still for two seconds; (b) Lift the object naturally and symmetrically, while keeping the arms suspended straight down and perpendicular to the ground. Following a few practice lifts, each subject twice lifted each of the 2.27, the 4.54, and the 6.81 kg objects in a randomly selected order.

Later, the subject was instructed to perform the squat lift as follows: (a) Approach the object as close as possible and stand still for two seconds; (b) Squat while maintaining the trunk straight and as near vertical as possible; (c) Lift the object keeping it between the knees and close to the body while maintaining the body erect and the arms suspended straight down and perpendicular to the ground. Following another few practice lifts, the subject then lifted the various objects in a randomly selected order using the squat method.

\[ \text{WORK} = \sum_{i=1}^{5} m_i h_i \]

The instructions for both the stoop and the squat lifting trials were also given to each subject on a sheet of paper and demonstrated by a video system.
**Filming procedures.** A motor driven, 16 mm Photosonics camera was used to film the subjects. The camera was located 8.06 m from the filming plane and was positioned such that its optical axis was perpendicular to the filming plane at its mid-point. The camera was placed on a tripod. The camera was positioned 1.07 m from the floor and parallel to it. A 25 mm focal length lens was used. The film used was Kodak RAR film 2498 ASA 250. The speed of the camera was set at 50 frames per second with a shutter factor of four. Therefore, each frame had an exposure time of 1/200 of a second. A controlled pulse generator was used to activate the camera's internal timing lights at a frequency of 100 Hz. The f-stop was set on four, and the focus was set near infinity. A D.C. battery pack was used to power the camera. Eleven projectors of 1,000 watts each provided the necessary level of light for filming.

**Electromyographic procedures.** A Beckman type R611 was used for recording the EMG activity of the quadriceps muscle. The paper had a speed of 250 mm per second. Bipolar surface electrodes were applied to the bellies of the vastus medialis (VM), the rectus femoris (RF), and the vastus lateralis (VL) of each subject. Activation of a marker switch was used to trigger a light and make a mark on the EMG record. This was done to synchronize the EMG and the film records.

**Maximal contraction procedures.** After performing the various lifts, several isometric knee extensions were performed on a Cybex for normalization purposes. The paper speed of the Cybex record was 50 mm per second. The subject was seated on the Cybex chair, with his right knee positioned to coincide with the axis of the Cybex arm. The subject’s shank was positioned at 120 degrees with respect to the thigh. The length of the Cybex arm was adjusted to the length of the shank such that the end of the Cybex arm reached the subject’s ankle. The Cybex arm was fastened to the ankle and a pad was placed between the Cybex arm and the subject’s ankle.

The subject was asked to extend his knee as quickly as possible, without any jerky movement, for approximately five seconds. Three practice trials were performed prior to the actual three isometric knee extension trials. Measurements were taken of both the EMG activity of the quadriceps muscle and the torque applied on the Cybex arm. The peak values of these EMG and torque data were then used as base lines for normalizing the peak EMG and the peak moment data obtained from the various lifts.

**Data reduction.** All the film record frames of the lifting phase, including five frames before and after the lift, were digitized using a Vanguard Motion Analyzer and a Numonics digitizer. The data were recorded directly onto a Sperry 1100/92 computer. A computer program then performed the following functions: (a) computing each segmental center of gravity using location parameters expressed as a percentage of total distance from the segment’s proximal end (Clauser, McConville, & Young, 1969); (b) smoothing the raw displacement data of the segmental center of gravity using a cubic spline procedure; (c) computing segmental masses using the body weight and the segmental weight parameters expressed as a percentage of body weight (Clauser et al., 1969); and (d) computing the history of the moment about the knee and the total work performed at the beginning and at the end of the movement according to above-stated Equations (1) and (2). The peak moment about the knee was averaged over the three trials for each lifted object and for each lifting method and then normalized with respect to the highest torque amplitude obtained from the maximal isometric contraction.

The highest EMG amplitudes of the vastus medialis, the rectus femoris, and the vastus lateralis were identified in each lift and then averaged for each lifting method and for each lifted object. The highest EMG amplitudes of the three maximal isometric knee extensions were also identified for each of the three heads of the quadriceps muscle. The average values, taken from the lifting trials, were then normalized with respect to those obtained from maximal extensions.

**Statistical analysis.** For each object lifted and for each lifting method, the means and standard deviations of the following vari-
TABLE 1
MEANS (X) AND STANDARD DEVIATIONS (SD) OF MECHANICAL AND EMG VARIABLES OBTAINED FROM LIFTING 2.27, 4.54 AND 6.81 KG OBJECTS USING THE STOOP AND THE SQUAT LIFTING METHODS

<table>
<thead>
<tr>
<th>Variable</th>
<th>2.27 kg</th>
<th>4.54 kg</th>
<th>6.81 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stoop</td>
<td>Squat</td>
<td>Stoop</td>
</tr>
<tr>
<td>PMOM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.69</td>
<td>6.65</td>
<td>-0.12</td>
</tr>
<tr>
<td>SD</td>
<td>1.74</td>
<td>2.37</td>
<td>1.31</td>
</tr>
<tr>
<td>WORK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>57.89</td>
<td>39.47</td>
<td>48.59</td>
</tr>
<tr>
<td>VM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.14</td>
<td>0.81</td>
<td>0.16</td>
</tr>
<tr>
<td>SD</td>
<td>0.20</td>
<td>0.34</td>
<td>0.27</td>
</tr>
<tr>
<td>RF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.11</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>SD</td>
<td>0.15</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>VL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>0.14</td>
<td>0.71</td>
<td>0.16</td>
</tr>
<tr>
<td>SD</td>
<td>0.19</td>
<td>0.18</td>
<td>0.11</td>
</tr>
<tr>
<td>DUR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>2.39</td>
<td>2.35</td>
<td>2.48</td>
</tr>
<tr>
<td>SD</td>
<td>0.35</td>
<td>0.32</td>
<td>0.34</td>
</tr>
</tbody>
</table>

* Positive and negative PMOM causes knee flexion and extension, respectively.

variables were calculated: the peak moment about the knee (PMOM); the total WORK; the peak EMG amplitude of the VM, the RF and the VL; and the duration of the total lift (DUR). Then, a discriminant analysis with a stepwise selection was applied to the variables in order to discover which of these variables maximally distinguishes the stoop from the squat lifting methods. A correlation matrix of these variables was also computed in order to verify that no important variable was eliminated during the selection phase of the discriminant analysis.

Another discriminant analysis with a stepwise selection was later applied to the VM, RF, and VL variables in order to form the QUAD variable, representing the peak EMG activity of the entire quadriceps muscle. Finally, a 2 x 3-repeated-measure analysis of variance (ANOVA) was applied to the PMOM, WORK, DUR, and QUAD variables in order to detect significant differences between the means of these variables for the two lifts.

RESULTS

Table 1 exhibits the mean (X) and standard deviation (SD) of the investigated variables for each lifted object and for each lifting method. For each of the lifted objects the variable PMOM — representing the normalized peak moment about the knee generated by the weight of the upper body, the thighs, and the lifted object — is much greater for the squat lifting method. These results are illustrated in Figure 2. The values for PMOM for each of the squat lifts are positive. However, the values for PMOM for the stoop lifts are much smaller.

4Essentially, QUAD is a linear combination of VM, RF and VL that maximally distinguishes the stoop from the squat lifting method.
In fact, for two of the three stoop lifts, PMOM even has a negative value. The negative value for PMOM suggests that the moment tends to extend rather than flex the knee.

The normalized peak EMG activity of the VM, the RF, and the VL correspond to those of the PMOM variable. Compare Figure 2 and Figure 3. Just as for PMOM, the values for the variables VM, RF, and VL are greater for the squat lifts than they are for the stoop lifts. The levels of EMG activity exhibited during the squat lifts more than twice exceed those exhibited during the stoop lifts. This is true for each of the recorded muscles.

The negative values for the WORK performed (see Table 1) represent the gain in potential energy that occurs during the lifting phase of each lift. A greater absolute value for the WORK variable represents a greater gain in potential energy. Indeed, the increase in
FIGURE 4
A COMPARISON OF THE TOTAL MECHANICAL WORK PERFORMED WHEN LIFTING OBJECTS USING THE STOOP AND THE SQUAT LIFTING METHODS

potential energy exhibited during each of the squat lifts is greater than that exhibited during each of the stoop lifts. This is true for each of the lifted objects (see Figure 4).

When the discriminant analysis using a stepwise selection was applied to these findings, the PMOM, RF, WORK, and VL variables entered the analysis, in that order. The results of the F-tests performed in the selection process reveal that the VM and DUR variables were removed from the analysis due to their lack of significance. The correlations between DUR and all the other entered variables and VM and all the other entered variables were examined for each of the lifts and were found to be low. Furthermore, the discriminant analysis did not exclude any of the test subjects.

The repeated measure ANOVA revealed that univariate F-tests across lifting methods were significant at a level of .01 for the PMOM, QUAD, and WORK variables (F = 17.03 for PMOM; F = 51.06 for QUAD; and F = 68.65 for WORK); however, they revealed no significant difference for the DUR variable. The univariate F-tests across lifted objects revealed a significant difference only for the WORK variable (p < .01 and F = 23.288).

DISCUSSION

The entrance of the PMOM into the first discriminant analysis clearly reflects the importance of this factor in maximizing the difference between the stoop and the squat lifting methods. In addition, the RF variable was the second variable to enter into this analysis, demonstrating that the knee extensor corresponds to the moment about the knee. These findings strongly support the claim that, among the investigated variables, the primary factor in the selection of the stoop as opposed to the squat lifting method can be found in the moment about the knee, generated by the weight of the upper body, the thigh and the lifted object.

Correspondingly, the rectus femoris, as the prime knee extensor, plays a very important role in counteracting this large moment. The next variable to enter into the analysis was the WORK variable, revealing that the additional mechanical work required to perform the squat method is also an important factor. The discriminant analysis method is greatly affected by the intra-correlations between the analyzed variables. If there are variables that are highly-correlated among themselves, then this type of analysis enters one of them while removing the others during the selection process. Thus, it is theoretically possible that a very important variable can be removed from the analysis. To make certain that this did not occur, an examination was made of the correlations between DUR and VM — the variables removed from the analysis during the selection process — and all the other entered
variables for each of the lifts. The examination revealed that DUR and VM had been excluded because they were not significant variables and not because they were highly-correlated with any other entered variable. Thus, this characteristic of discriminant analysis did not jeopardize the interpretation of these findings.

The entrance of each variable into the analysis is statistically significant, since the fundamental selective mechanism in the discriminant analysis is based on repeated $F$-tests that are administered for each entrance or removal of a variable (Pedhazur, 1982). The fact that none of the excluded variables were significant and that none of the test subjects were excluded demonstrates the superb quality of the results of the discriminant analysis.

Figure 5 depicts one of the subjects lifting a 2.27 kg object using the stoop and the squat lifting methods. In addition, an EMG record is given to show the level of EMG activity at progressive stages during each of the two lifts. The time increments depicted are identical for each lift, namely every 0.199 of a second. In addition, each of the lifts depicted were identical in duration. It should be mentioned here that it was very difficult to detect the precise timing of both the beginning and the termination of each lift. At these stages of the motion, the body tends to oscillate and move very gradually for a substantial amount of time with respect to the duration of the overall lift. This oscillatory and gradual motion prevented the accurate detection of these points in time. It is therefore believed that this was the reason for our not being able to detect the hypothesized difference in the duration of the two lifts.

At the beginning of the squat lift, almost all the body mass as well as the mass of the external lifted object is located behind the knee (see Figure 5a). By contrast, at the

FIGURE 5
A SAMPLE OF A FILM AND ITS CORRESPONDING EMG RECORD OF (A) THE SQUAT AND (B) THE STOOP LIFTING METHODS
beginning of the stoop lift, only the lower part of the trunk and the thigh are located behind the knees, while the upper part of the trunk and the arms as well as the lifted object are located in front of the knees (see Figure 5b). This clearly demonstrates the source of the large flexion moment about the knee, which the quadriceps muscle has to overcome at the beginning of the lifting phase of the squat lift. These findings are also supported by Nisell’s (1985) findings.

A negative value for PMOM in this study means that the peak moment about the knee has actually caused a knee extension rather than a knee flexion. It is not surprising that quite often a very small value, or even a negative value, for the peak moment about the knee is obtained in the stoop lifting method (see Figure 5b). This small or negative value suggests that very little effort is expended by the quadriceps muscle in order to maintain knee posture when the stoop lift is performed. By contrast, the EMG records reveal that much greater demand must be overcome by the quadriceps muscle in order to perform the squat lift. See Figure 3 and Figure 5.

The fact that the WORK variable enters the discriminant analysis also suggests that the relatively greater degree of mechanical work required to perform the squat lift has a substantial influence on our tendency to select the stoop lifting method (see Figure 4).

CONCLUSIONS

Humans may naturally prefer the stoop lift method to the squat lift method because of the greater demand the squat lift imposes on the knee extensors. The relatively greater mechanical work required to perform the recommended squat lift is also an important factor in explaining why humans naturally prefer the stoop lift method. These conclusions are limited to the lifting of small objects weighing 6.81 kilogram or less.

REFERENCES


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