Morphology-Related Isometric Trunk Strength of South African Manual Workers: Implications for Prevention of Occupational Low-Back Stress

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Occupational back stress among manual workers in South Africa is now a cause of governmental concern. Yet no data on the back strength of the South African workforce have been published. This study represents a first step in reporting the trunk strength of Xhosa workers in South Africa, in absolute and size-relative terms. Thirty-five male manual workers were tested isometrically while making maximal extension and flexion efforts at 0°, 23°, 46°, 69°, and 92° of stoop. The results show nonlinearity of the extensor-to-flexor (E/F) ratio of the trunk musculature. The E/F ratio increases in deep stoop because of a drop in flexor torques. The data suggest that predictions of flexor from extensor torques or vice versa can confidently be made so long as testing is done away from the fully flexed position. Significant differences between morphologically gracile and robust workers in this sample are discussed. The study has implications for occupational rehabilitation and for prophylaxis, for whereas muscular strength alone may not protect the spine from occupational injury, muscular weakness certainly predisposes it.

1. INTRODUCTION

For decades authors have reported very high frequencies of occupation-related back stress in industrially developed countries (Horal, 1969; Klein, Jensen, & Sanderson, 1984; Svensson & Andersson, 1982). More recently, manual materials handling has been implicated as the dominant factor in workplace back injury (Allread, Marras, & Parnianpour, 1996; Bigos et al., 1986; U.S. Department of Labor, 1989). There is reason to suppose that this phenomenon is even more serious in South Africa, an industrially developing country where materials handling is very labour intensive (Charteris & Scott, 1993). Indeed, the incidence of occupational back stress among manual workers in South Africa has led to government-sponsored research aimed at reducing its rate and severity (Charteris & Scott, 1993). The problem is compounded by the fact that no data exist on the trunk strength of African workers, and nothing is known of the relationship of trunk strength and physique in the indigenous South African population.

The aim of this research was to establish benchmark data on a cross-sectional sample of Xhosa-speaking manual workers, via isometric strength testing of trunk flexors and extensors through a functionally normal range of stooping positions, and to get some idea of the degree of relationship between trunk strength and physical robusticity. Our purpose was to suggest directions for further research, not to make definitive statements relating to the entire nation.

A great deal of low-back pain (LBP) is muscular in origin (Sarno, 1978), and muscular weakness, whether as cause or effect, is often associated with LBP (Mayer, Smith, Keeley, & Mooney, 1985; Suzuki & Endo, 1983). Undoubtedly, trunk muscle strength requisite to the participant’s lifestyle is important in the prophylaxis of LBP syndrome. Whereas muscular strength alone will not protect a manual worker’s back, it is clear that muscular weakness does...
TABLE 1. Participant Characteristics

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Stature (mm)</th>
<th>Mass (kg)</th>
<th>RPI stature/3/mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>40.1</td>
<td>9.6</td>
<td>1,714</td>
<td>52.0</td>
</tr>
</tbody>
</table>

expose employees in any category of work to increased risk of debilitating LBP incidence particularly where stooping is involved (Chaffin, 1974; Marras et al., 1995; Mital, 1986; Mital & Das, 1987).

Despite a very extensive literature on the subject, there has been surprisingly little done on the assessment of full-range muscle strength of the trunk in terms of agonist-antagonist relationships under conditions simulating natural patterns of stooping to lift heavy objects. In fact, clinicians have been at pains to test trunk flexion and extension under constraints which so stabilize the pelvis as to isolate the lumbar region and eliminate, as far as possible, natural contributions from hamstrings, glutei, and adductor muscles during trunk extension (Cailliet, 1981; Smidt et al., 1983). In the process, the normal range of motion studied is sometimes significantly reduced (see Langrana, Lee, Alexander, & Mayott, 1984). As recently as 1990, Graves and coworkers could find only two studies in which isometric strength testing of the lumbar spine had sampled in more than one position. The present study samples trunk extensor and flexor isometric maxima at five-step intervals through just over 90° of sagittal range in a carefully stabilized lower extremity posture. Whereas Graves et al. (1990) had tested only extensor strength, through barely 70° of trunk flexion, this study has extended the range to more than 90° and assessed flexor strength, extensor strength, and the changing relationship between these through the range of motion; as, for example, when a worker stoops to lift an object.

The major contribution of this article, however, is that it offers data on the maximal sagittal trunk strength of a population not hitherto studied but upon whose physical capacities South African industry relies: the predominantly black male manual workforce.

2. METHOD

Thirty-five healthy adult South African male manual workers (age range: 20-60 years) volunteered as participants in this study. All were Xhosa-speaking members of the same community, with diverse manual materials handling occupations under one employer.

Participants were tested isometrically on a Cybex 6000 Isokinetic Dynamometer with attached trunk extension-flexion (TEF) module for sagittal assessment of extensor and flexor torques. The system itself is as described by Timm (1987).

Given the wide-ranging literacy levels of the volunteer cohort, particular attention was paid to ensuring that consent was both freely given and fully informed.

2.1. Participant Selection

The inclusion criteria were as follows:

1. Voluntary participation, with neither peer nor experimenter pressure to participate. The employer, having given blanket consent, had no further involvement in the selection process.
2. Absence of any history of occupational back pain or of any joint disorder, as far as could be ascertained from medical records and volunteer recall.
3. Since participants were being asked to make maximal efforts and because levels of literacy varied considerably in the worker cohort, rigorous application was made of a procedure by which each participant’s foreman, working compatriot, or both were present throughout and encouraged to interact. Additionally, a competent interpreter, representing the workers, relayed information, answered questions, and contributed generally to the relaxed atmosphere characterising the testing. Any hint of participant anxiety was addressed by an easing of requirements and casual conclusion of the session with the data being aborted subsequently. In only one case was an older worker sufficiently anxious that the data could not be used.

2.2. Participant Position
The Cybex TEF modular component very specifically controls participant positioning and stabilization so as to ensure test–retest standardisation and interparticipant postural control. This procedure has been well documented in the literature (Smith, Mayer, Gatchel, & Becker, 1985). The setup is depicted in Figure 1, and the following brief description suffices. Each participant was positioned so that the palpated L5/S1 articulation, the assumed centre of rotation, was aligned with the input axis of the TEF module. This was done by palpation of the

Figure 1. Participant in position on a Cybex 6000 TEF module. Position indicated is a 69° stoop, and participant is making a maximal extension effort.
iliac crests and assuming the position of L5/S1 to be 2% of stature caudal to that level. The TEF device locks thigh and shank (via anterior pads and a posterior popliteal pad) in 15° to 20° of flexion at the knees.

In slight modification of the manufacturer’s setup, we allowed each participant to hold the chest pad (against which trunk flexion efforts would be made) at a freely chosen midsternal level and then aligned the corresponding back pad (against which extension efforts would be made) accordingly. This procedure was deemed psychophysically and kinesiologically superior.

2.3 Test Procedure
Following verbal instructions, which were reinforced by an interpreter to ensure that second-language English speakers were fully informed and socially comfortable with the procedures, participants were habituated to the required maximal efforts expected by requesting them, at leisure, to make 50%, 75%, and near-maximal efforts of a few seconds’ duration with ample rest and performance feedback between efforts. Minor comfort-related position adjustments were made during this phase, and participants were asked to introspect with respect to the efforts made. Under test conditions the five isometric effort positions of the trunk (0°, 23°, 46°, 69°, and 92° flexion) were randomly presented, except that 0° and 92° positions were never the first efforts made. The participant was moved to the randomly ordered position, was locked in place, and then was required to make a maximal effort (either flexion or extension) of 3-s duration. This was followed by a return to neutral upright position and a minute-long rest during which verbal feedback was given and the participant was informed that the next effort, from the same position, would be a reciprocal effort (flexion after an extension, or vice versa).

During the testing, consistent verbal encouragement following Smidt et al. (1983) was given to ensure motivation to output maximally. Following the paired extension and flexion maximal efforts in each of the five test positions, participants were removed from the device and given immediate feedback on their performances with brief explanations of the results.

3. RESULTS
3.1. Posture and Truncal Strength
Clearly, extensor torque increases steadily as efforts are made from more stooped positions. We contend that this is due in part to the improved length–tension relationship in the erector spinae, and in part also to increasing recruitment of pelvo-femoral muscles such as hamstrings and glutei, as stoop level increases. The results are depicted in Figure 2.

Clearly also there is a significant change in flexor torque only once the trunk has flexed past about 70°. This is probably so because, in more erect positions, much of the action of rectus abdominis and iliopsoas is vertically compressive on the spine, only contributing predominantly to flexion once the sternum is well forward of the hips. The flexor torque levels off as the trunk hunches and the flexors increasingly lose length–tension advantage. Beyond 70° of trunk flexion, the flexor torque drops significantly due to a very unfavourable length–tension relationship. The effect of this is that the difference between extensor and flexor torques becomes disproportionately large over the final third of the trunk flexion range.

The torques shown in Table 2 and Figure 2 have been corrected for gravitational influence. Trunk extension torque from a stooped position must overcome trunk weight before any upward motion occurs. Conversely, trunk flexion torque, as recorded, includes the nonmuscular moment due to trunk weight, so that the effect of gravity must be corrected by adding trunk-mass torque to the registered extensor torque and by subtracting it from the registered flexor torque. This manipulation gives a better understanding of the actual musculoskeletonally generated torques involved. It has been argued that gravity correction is unnecessary because trunk flexion and extension in everyday life occur in a constant gravitational environment. This reasoning may hamper a clear understanding of the causes of LBP incidents, for when one
### TABLE 2. Mean Sagittal Plane Maximal Isometric Trunk Extension and Flexion Torques ($T_{\text{max}}$)

<table>
<thead>
<tr>
<th>Direction of Effort</th>
<th>Peak Torque</th>
<th>Position</th>
<th>$0^\circ$</th>
<th>$23^\circ$</th>
<th>$46^\circ$</th>
<th>$69^\circ$</th>
<th>$92^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Extension (E)</td>
<td>Nm</td>
<td>199</td>
<td>78.3</td>
<td>290</td>
<td>95.1</td>
<td>323</td>
<td>90.1</td>
</tr>
<tr>
<td></td>
<td>Nm·kg$^{-1}$</td>
<td>2.92</td>
<td>4.23</td>
<td>4.76</td>
<td>5.31</td>
<td>5.59</td>
<td></td>
</tr>
<tr>
<td>Flexion (F)</td>
<td>Nm</td>
<td>182</td>
<td>55.5</td>
<td>184</td>
<td>44.9</td>
<td>191</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td>Nm·kg$^{-1}$</td>
<td>2.63</td>
<td>2.70</td>
<td>2.80</td>
<td>2.91</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>E/F Ratio</td>
<td></td>
<td>1.1</td>
<td>1.4</td>
<td>1.3</td>
<td>1.4</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Mean extension (E) and flexion (F) torques with increasing stoop. Note the widening disparity between the means, as a function of trunk flexion position.
Figure 3(a). Flexion plots to show 95% confidence intervals for factor means. Groups that are not significantly different ($p < .05$) are boxed together.

Figure 3(b). Extension plots through the range of positions tested. Convention is described in Figure 3(a).
TABLE 3. Gracile Versus Robust Morphology and Associated Strength

<table>
<thead>
<tr>
<th>Variables</th>
<th>Units</th>
<th>Most Gracile</th>
<th>Most Robust</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>years</td>
<td>40.3 (12.4)</td>
<td>40.8 (8.3)</td>
<td>ns</td>
</tr>
<tr>
<td>RPI</td>
<td>—</td>
<td>461.0 (15.4)</td>
<td>390.4 (7.7)</td>
<td>s</td>
</tr>
<tr>
<td>stature/√mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Strength (Highest Ext + FLEX Torque)</td>
<td>Nm</td>
<td>490 (73)</td>
<td>711 (168)</td>
<td>s</td>
</tr>
<tr>
<td>Stature</td>
<td>mm</td>
<td>1,740 (68)</td>
<td>1,700 (33)</td>
<td>ns</td>
</tr>
<tr>
<td>Mass</td>
<td>kg</td>
<td>(55.8)</td>
<td>82.2 (8.3)</td>
<td>s</td>
</tr>
<tr>
<td>Total Strength/Mass</td>
<td></td>
<td>8.78</td>
<td>8.65</td>
<td></td>
</tr>
</tbody>
</table>

Note. RPI: reciprocal of the ponderal index.

When stoops to pick up a pencil it is the weight of head, arms, and trunk (which approximates 75\% of body weight) plus the weight of the pencil that must be lifted.

Also noteworthy, but not shown hitherto in studies involving more limited ranges of motion, is the levelling off of extensor torque maxima in extreme stoop, there being no significant differences in extensor torques beyond 46°. It is useful also to quantity muscular strength in units factored for body mass, because bigger persons, although absolutely stronger, are relatively weaker than smaller individuals (see Table 3).

The agonist–antagonist ratios (Figure 4) were revealing, particularly in light of the assertion of Reid, Hazard, and Fenwick (1991) that most authors agree that in healthy participants there

Figure 4. Extensor-to-Flexor ratio (E/F) shown in terms of 95\% confidence intervals for factor means. As in Figure 3, groups that are not significantly different are boxed together.
is an extensor-to-flexor ratio between 1.2 and 1.4. The extensor-to-flexor (E/F) ratio remained constant at about 1.37 throughout the middle half of the range of motion tested and was significantly higher (2.1) at 92°, not by virtue of any significant effect of the extensors, but because of demonstrably lower flexor torques in the fully flexed position. This finding alone is of great relevance to sagittal plane muscle testing of the trunk. Apparently, confident predictions of flexor strength (about 0.76 extensor maximum) or extensor strength (about 1.32 flexor maximum) can be made for large-scale (isometric) industrial screening and similar purposes, so long as testing is done away from the fully flexed position.

4. DISCUSSION

It is presently very difficult to compare studies from the literature given the diversity of protocols and device constraints used. Langrana et al. (1984) specifically implicate differences in “lever arm length, posture and race” as reasons for differences in findings of researchers working on diverse populations. Thus, Smith and colleagues (1985), working on a wide age range of relatively sedentary American males and testing isometrically only in the upright position, obtained values slightly higher than ours for extension (T\(_{\text{max}} = 215.2\) Nm) and significantly lower for flexion (T\(_{\text{max}} = 152.5\) Nm), resulting in an E/F ratio of 1.4, against ours of 1.1 (see Table 2).

On the other hand, Hasue Fujiwara, and Kikuchi (1980), working at very low isokinetic speeds (6°-s\(^{-1}\)), had obtained results almost identical to ours for maximal extension torque (192.3 Nm) and almost identical to those of Smith and coworkers (1985) for maximal flexion (158.6 Nm), yet for participants who performed in lying positions working against gravity. Presumably the congruence of these data reflect in part at least similar trunk–thigh relationships and consequently similar contributions from the bi-articular muscles that contribute to trunk flexion and extension, such as the hamstrings and iliopsoas. Langrana and coworkers (1984) obtained significantly higher isometric extensor maxima (239 Nm) and significantly lower flexor maxima (130 Nm), resulting in an E/F ratio of 1.84; but their participants performed through a restricted range of motion in which trunk-on-thigh flexion was never less than 50° and in which the participants were strapped down in a seated position specifically designed to nullify the contributions of bi-articular muscles. Although the aforementioned isometric maxima were recorded in truncal postures close to our 0° position, the actual extent of trunk-on-thigh flexion was apparently about 90° for the flexion effort, in which case their 130 Nm compares favourably with our value of 133 Nm at 92° stoop. This discussion highlights the importance of always referring trunk strength data to the specific conditions under which they were collected. In the absence of a consensus on standardisation of test conditions, the meaning of E/F values cannot be generalised, either for rehabilitational purposes or prophylactically in screening suitable workers for manual materials handling operations involving stooped lifting. Despite these cautions, all researchers are clear that the E/F ratio, however tested, always exceeds 1.0; trunk extensors are stronger than flexors.

This article demonstrates that through the full range of motion normally adopted for occupational lifting using a trunk-on-limb posture which is not esoteric, the E/F ratio is about 1.4 for most of the range of motion, being slightly less at the start of stooping and becoming significantly greater towards the end of trunk flexion.

Several cautions need to be mentioned with respect to our findings, not least among them that with a small sample (N = 35) no normative inferences are justified from these data. Nor are the absolute values presented here necessarily representative of the capacities of specifically selected healthy young adults in peak condition. Our express purpose was to sample widely with respect to age, physique, work capacity, and health status and to stipulate only two criteria, that maximal efforts be made and that participants with contraindicating medical histories be excluded. In neither of these could we do more than take reasonable precautions. Care was taken to ensure that workers who remained anxious under laboratory test conditions were not included in the sample. We were satisfied that participants worked maximally given
that repeated testing of some participants, with several days between tests, confirmed low (< 5%) test-to-test variability (Graves et al., 1990).

4.1. Morphology and Truncal Strength
The anthropometry of black South African male workers relevant to this discussion is fairly well established (Jürgens, Dune, & Pieper, 1990; Wyndham, 1975), although more recent studies have suggested slight increases in adult height and weight over those reported 2 or 3 decades ago. Our samplings around the country suggest that an adult male stature of 1,714 mm and mass of 67.9 kg may be closely representative of the population mean.

The ponderosity index expresses body mass per unit stature in the allometric form of a dimensionless ratio (\(\frac{\sqrt[3]{\text{mass}}}{\text{stature}}\)), but its reciprocal, stature (mm)/\(3\sqrt[3]{\text{mass}}\) (kg), is a useful measure of linearity of physique. In the study of athletic and active manual working populations, it is more useful to relate performance to the reciprocal of the ponderal index (RPI). Similarly, when normal weight-for-height tables are consulted for superior athletes, the latter often spuriously appear to be in categories usually associated with health risk. This is due to the fact that what might seem to be an abnormal mass–stature relationship is not; among elite athletes, it is a function of large amounts of adipose tissue but rather it is a function of well-conditioned muscle.

We did not estimate the percentage of fat and lean body mass components of our participants, but the sample was subjectively noted to include no endomorphs. We attribute the significant inverse relationship between trunk strength and RPI scores to be due to the fact that the “ponderosity” represented by the lower RPI scores was in the form of lean body mass, hence of higher muscularity. In many populations, mass relationships not compartmentalised into fat and lean tissues are of low utility in predicting strength, but in others, where participants are much more uniformly composed in terms of stature and mass, the RPI may be a useful indicator. Thus, Samanta and Chatterjee (1981) observed that Indian manual labourers were very uniformly close to 1,637 mm stature and 47.3 kg mass (i.e., closely distributed about RPI 453, suggesting a very gracile physique). Where obesity is rare and morphological homogeneity is evident, as among Indian manual workers, the relationship between muscular strength and RPI may be expected to be sufficiently high to be of some utility as a screening device for worker placement; low RPI values represent in this case a measure of robusticity highly related to overall muscularity rather than ponderous obesity. This is a suggestion worth testing in the context of the South African labour force in situations where lifting of objects is still largely manual.

We found an interesting relationship between trunk strength in all tested positions and the RPI. In every instance, the mean flexor and extensor strength of the six most linear participants \((M \text{ RPI} = 461.0)\) was less than that of the six most ponderous participants \((M \text{ RPI} = 390.4)\). Since ponderosity measures overall mass, not lean body mass, and because adipose tissue contributes nothing to strength expression, it is usual to find little relationship between ponderosity and strength. However, in this study, the statures and ages of these groups were not significantly different, although the mean body mass difference (17.7 kg) was significant. Thus, the relative RPI differences were mediated by differences in body mass. This implies that the relative ponderosity or linearity we were measuring was largely in respect of the muscular component. When total strength was related to body mass in each of the subgroups, the result showed the more massive participants to be statistically no different from their more gracile counterparts.

5. CONCLUSIONS

5.1. Truncal Strength
In a sample of 35 healthy black male manual workers (age range: 20–60 years) tested isometrically through the range of stooping normally associated with heavy object lifting, we found
trunk extensor torque to be positively related but not linearly so: Greatest trunk extension torque (382 Nm) was in the position of greatest stoop (92°), and greatest flexion torque (191 Nm) was in the position of midstoop (46°). The extensor-to-flexor ratio was relatively constant through the midrange, but highest where extension was strongest and flexion weakest, at 92° trunk flexion.

5.2. Positioning for Maximal Trunk Strength Tests

In extension, there is a progressive increase in isometric $T_{\text{max}}$ with an increasing angle of stoop. Testing around 0° flexion produces significantly lower values than in positions greater than 20° flexion, presumably because hip extensors then come into play as well. Further increases in the range between 20° and 50° of stoop can be expected not to be significant, but there is a significant increase over these midstoop extensor torques in the last half of the range of motion. In flexion from 0° to 69° of stoop there are no significant differences. All differences that occur are in conjunction with significant decreases after 69°.

In combination, slight stoops will affect extension torques, and great stoops will affect flexion torque. To ensure that maximal flexion and extension torques are recorded, any position of stoop between 30° and 60° would seem to suffice, and no greater control of position seems necessary. We suggest that a position of 45° (10° more or less) would ensure attainment of maximal isometric torques while at the same time meeting psychophysical criteria of acceptability and logistical criteria of feasibility.

5.3. Morphology and Trunk Strength

Where morphology is more homogeneous, as reported among male labourers in Southern India, strong relationships between RPI and muscular strength can be expected: That is, where obesity is rare, increased mass will more likely be indicative of muscle bulk and, hence, strength. Among South African manual workers, there is greater nutritional diversity, less homogeneity of morphology, and hence a less strong relationship.

This study, however, suggests that there is a need to address the relationship between robusticity of physique, trunk strength, and work-related back-stress incidence. We do not, on the basis of our small sample, advocate screening of manual workers for lifting tasks using the RPI alone as an indicator of vulnerability.

However, we have shown here that age- and stature-matched workers of more gracile build, whose strength-to-mass ratios are similar to those of their more robust counterparts, are working at significantly greater percentages of maximal effort: Our gracile group was 84% as robust and only 69% as strong in absolute terms. The implications of this, for injury prevention and work hardening, merit serious consideration.

REFERENCES


