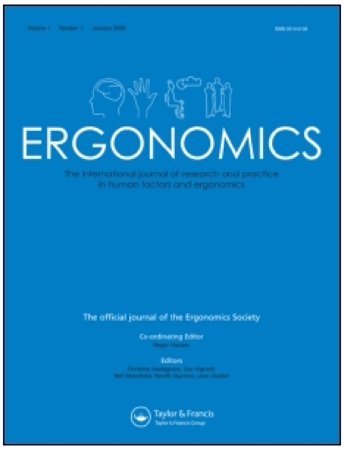

Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713701117

Obesity effect on male active joint range of motion

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Online publication date: 12 January 2010

To cite this Article Park, Woojin, Ramachandran, Jaiganesh, Weisman, Paul and Jung, Eui S.(2010) 'Obesity effect on male active joint range of motion', Ergonomics, 53: 1, 102 — 108
To link to this Article: DOI: 10.1080/00140130903311617
URL: http://dx.doi.org/10.1080/00140130903311617

Ergonomics
Vol. 53, No. 1, January 2010, 102–108

Obesity effect on male active joint range of motion

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(*Received 28 July 2008; final version received 3 September 2009*)

Despite the prevalence of obesity, how obesity affects human physical capabilities is not well documented. As an effort toward addressing this, the current study investigated the obesity effect on joint range of motion (RoM) based on data collected from 20 obese and 20 non-obese males. In total, 30 inter-segmental motions occurring at the shoulder, elbow, knee and ankle joints and lumbar and cervical spine areas were examined. The obesity effect was found to be non-uniform across the joint motions. Obesity significantly reduced RoM for nine of the 30 motions: shoulder extensions and adductions, lumbar spine extension and lateral flexions and knee flexions. The largest significant RoM reduction was 38.9% for the left shoulder adduction. The smallest was 11.1% for the right knee flexion. The obesity-associated RoM reductions appear to be mainly due to the mechanical interposition and obstruction of inter-segmental motions caused by excess fat in the obese body.

Statement of Relevance: Currently, obesity is prevalent worldwide and its prevalence is expected to increase continually in the near future. This study empirically characterised the obesity effects on joint RoM to provide better understanding of the physical capabilities of the obese. The study findings will facilitate designing man–artefact systems that accommodate obese individuals.

Keywords: obesity; fatness; body joint motions; range of motion

1. Introduction

Joint range of motion (RoM) is the measure of motion available at a body joint for a certain inter-segmental rotational movement. Joint RoM at body joints has been an important research topic in physical ergonomics and related disciplines because they greatly affect individuals' physical capabilities to perform work and daily-life activities (Badley *et al.* 1984, Verbrugge and Jette 1994, Kee and Karwowski 2002) and, therefore, are an important consideration in the design of products, workplaces and living environments (Kee and Karwowski 2002, Zhang *et al.* 2005). Joint RoM is also clinically important. Normative RoM based on large samples of data can serve as a useful reference when quantifying an individual's progress during a rehabilitation process and also evaluating efficacies of different rehabilitation programmes (Stubbs *et al.* 1993).

Joint RoM is primarily limited by the skeletal and muscle structures and functions and also the physiological characteristics of connective tissues surrounding a body joint (Alter 1996, Reese and Bandy 2002). It may vary across populations and can also be affected by certain intrinsic factors. Numerous studies have been conducted to provide RoM data for different populations and also to test and characterise the effects of intrinsic factors, such as age and gender. For example, Murray *et al.* (1985), Kuhlman (1993), Stubbs *et al.* (1993) and McGill *et al.* (1998) investigated the age-related changes of joint RoM for various body joint motions. Ferrario *et al.* (2002) and Sforza *et al.* (2002) studied the cervical spine RoM for the younger population. Hu *et al.* (2006) provided voluntary joint RoM data of the Chinese elderly in the Beijing area. Feipel *et al.* (1999) examined the age and gender effects on global cervical spine RoM. Doriot and Wang (2006) characterised the effects of age and gender on voluntary RoM of the upper body joint motions. Toren (2001) investigated RoM of truck drivers and provided estimates of measurements needed in the design of commercial vehicles and associated equipment.

Aside from age and gender, there may be multiple intrinsic factors that affect joint RoM. One such factor is obesity, which is characterised by excess fat in the human body. Obesity is prevalent worldwide at the

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ISSN 0014-0139 print/ISSN 1366-5847 online

DOI: 10.1080/00140130903311617
http://www.informaworld.com

present time (Mokdad *et al.* 1999, Flegal *et al.* 2002, Hertz *et al.* 2004, Baskin *et al.* 2005) and is predicted to continually increase in the near future (Flegal *et al.* 2002). Obesity is expected to reduce joint RoM as the adipose tissues around body joints would likely interpose and obstruct inter-segmental rotations (Laubuch 1969, Escalante *et al.* 1999a,b, Chaffin *et al.* 2006, Gilleard and Smith 2007). If obesity indeed has a significant effect on joint RoM, it should be characterised so as to provide a better understanding of the physical capabilities of the obese. Such understanding will facilitate designing man–artefact systems that accommodate obese individuals.

Despite the need, however, the effect of obesity on RoM is currently not well documented. Very few studies have examined the joint RoM of the obese. The authors are not aware of large-scale RoM databases pertaining to the obese or studies that comprehensively documented the obesity effect on RoM for various body joint motions. To address this, the goal of this study was to test and characterise the obesity effect on joint RoM for a number of upper and lower body joint motions. In total, 20 obese and 20 non-obese males participated in this study. For each participant, RoM data for 30 body joint motions were collected. For each joint motion, the mean RoM values of the obese and non-obese groups were statistically compared.

2. Methods

There were 20 obese and 20 non-obese male participants in this study. All the participants were relatively young, most of them being in their twenties and early thirties. The study participants were randomly recruited from the University of Cincinnati community. A study participant was classified as non-obese if his BMI was >20 kg/m^2 and <25 kg/m^2. A BMI >30 kg/m^2 was considered obese. The participants' body masses and heights were measured at the site of data collection and their BMI were calculated based on them. Individuals who had any obvious neurological, musculoskeletal and soft tissue disorders were excluded during the participant recruitment process. Also, athletes and individuals who were engaged in regular physical exercises for improving fitness or flexibility were excluded. A questionnaire containing all the exclusion criteria was used to assess physical eligibility of study participants. The questionnaire was developed by a licensed physical therapist. The participants' age, height, body mass and BMI data are summarised for each participant group in Table 1.

Prior to the data collection, each participant participated in an introductory session in which all the questions regarding the nature and protocol of the study were answered. No indications about the expectation of results were given in order to avoid conscious or unconscious bias of the results. All the participants signed an informed consent form prior to the data collection. The study was approved by the Institutional Review Board, University of Cincinnati Medical Centre.

For each participant, joint RoM measurements were conducted for a total of 30 joint motions (Table 2). Detailed descriptions of the motions' definitions and the standardised measurement procedures can be found in Reese and Bandy (2002). The definitions and methods described in Reese and Bandy (2002) are largely based on the recommendations by the American Academy of Orthopedic Surgeons (1965) and the American Medical Association (1993).

In a way similar to the procedure employed by Stubbs *et al.* (1993), one experimenter who had more than 6 months of extensive training and experience with RoM measurements collected all RoM data. Motion was measured to the nearest 1°. For each participant and each motion, two measurements were taken repeatedly until two readings were within 4° of

Table 1. Summary of the age, height, body mass and BMI data for the two participant groups.

	Obese	Non-obese
Dimensions	Mean ± SD	Mean ± SD
Age (years)	26.2 ± 5.6	22.3 ± 1.7
Height (cm)	177.8 ± 7.9	176.4 ± 7.6
Body mass (kg)	139.7 ± 29.7	70 ± 7.7
BMI (kg/m^2)	44 ± 7.4	22.5 ± 1.8

Table 2. Joint motions considered for the range of motion measurements.

Body joint or area	Type of motion
Cervical spine (neck)	Flexion (unilateral)
	Extension (unilateral)
	Rotation (left, right)
Shoulder	Flexion (left, right)
	Extension (left, right)
	Abduction (left, right)
	Adduction (left, right)
	Lateral rotation (left, right)
	Medial rotation (left, right)
Elbow	Flexion (left, right)
Lumbar spine (back)	Flexion (unilateral)
	Extension (unilateral)
	Rotation (left, right)
	Lateral flexion (left, right)
Knee	Flexion (left, right)
Ankle	Plantarflexion (left, right)
	Dorsiflexion (left, right)

each other. The mean of the last two measurements was used in the data analyses.

The back RoM instrument (BRoM II™; Performance Attainment Associates, Lindstrom, MN, USA) was utilised to measure RoM of the lumbar spine motions: lumbar spine flexion; extension; rotations; lateral flexions. Standard goniometers were used to measure RoM for the rest of the motions. The measurement devices were validated against known angles of 0°, 45°, 90°, 135° and 180°, again similar to the methods used by Stubbs *et al.* (1993).

For each of the two participant groups and each of the joint motions studied, descriptive statistics, such as mean and standard deviation, were computed to summarise the collected RoM data. For each joint motion studied, the mean RoM of the two participant groups were compared using an unpaired t-test, with equal means as the null hypothesis. In performing the t-tests, the Bonferroni correction was used to adjust for multiple comparisons: the 30 t-tests were separated into six groups corresponding to the six body joints/areas shown in Table 2. Within each group of t-tests, the familywise α was set at 0.05 and the testwise α for each t-test was determined by dividing the familywise α by the number of t-tests in the group.

3. Results

Table 3 summarises the RoM data measured for the motions at the cervical spine area. For each motion, the means and standard deviations for the non-obese and obese groups are provided. Also, the inter-group mean RoM difference (obese – non-obese) is presented as a percentage of the mean RoM of the non-obese group. Tables 4–8 provide similar summaries for the motions at the shoulder joints, elbow joints, lumbar spine area, knee joints and ankle joints. In the tables, statistically significant inter-group mean differences identified by t-tests are indicated with asterisks.

Among the motions at the cervical spine area, no joint motion was found to exhibit a statistically significant inter-group mean RoM difference (Table 3).

At the shoulder joints, the obese group was found to have a significantly smaller mean RoM than the non-obese for the shoulder extensions and adductions (Table 4). No significant inter-group mean differences were found for the other shoulder joint motions. The obesity-associated reductions in mean RoM for the left and right shoulder extensions were 22% and 20.5%, respectively. Those for the left and right shoulder adductions were 38.9% and 35.9%, respectively.

Table 3. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the cervical spine motions.

	Cervical spine motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Unilateral	Flexion	44.9 ± 5.7	40.4 ± 7.5	−10	0.0397
	Extension	72.2 ± 12.8	68.2 ± 12.1	−5.5	0.3162
Left	Rotation	75.2 ± 6.1	75 ± 7.1	−0.3	0.9243
Right	Rotation	75.6 ± 6.4	76.3 ± 5.8	0.9	0.7178

Note: No statistically significant difference found at Bonferroni-adjusted testwise α of 0.0125 (=0.05/4).

Table 4. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the shoulder joint motions.

	Shoulder joint motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Left	Flexion	161.5 ± 14.2	162.8 ± 16.3	0.8	0.7969
	Extension	51.6 ± 8.5	40.2 ± 11.4	−22*	0.0009*
	Abduction	157.7 ± 2.5	159.6 ± 22.3	1.2	0.8010
	Adduction	30.6 ± 6.8	18.7 ± 9.4	−38.9*	<0.0001*
	Lateral rotation	82.7 ± 5.8	76 ± 14.1	−8.1	0.0609
	Medial rotation	59.9 ± 12.4	59.4 ± 11.4	−0.8	0.9054
Right	Flexion	162 ± 14.6	163.9 ± 14.3	1.2	0.3462
	Extension	51.3 ± 8.1	40.8 ± 11.4	−20.5*	0.0017*
	Abduction	158.8 ± 23.6	158.7 ± 22.8	−0.1	0.9946
	Adduction	32.3 ± 7.5	20.7 ± 10	−35.9*	0.0002*
	Lateral rotation	83.6 ± 6.2	78.4 ± 14.3	−6.2	0.1508
	Medial rotation	60.6 ± 11.5	61 ± 10.3	0.6	0.9082

*Significantly different at Bonferroni-adjusted testwise α of 0.004167 (=0.05/12).

For the elbow flexions, the inter-group mean RoM differences were found to be statistically not significant (Table 5).

At the lumbar spine area, significant inter-group mean RoM differences were found for the extension and two lateral flexions (Table 6). The obesity-associated mean RoM reduction for the lumbar spine extension motion was 21.7%. The reductions for the left and right lateral flexions were 20% and 18.4%, respectively. The lumbar spine flexion and rotations did not show significantly large inter-group mean RoM differences.

For the knee flexions, the obese group was found to have significantly smaller mean RoM than the non-obese (Table 7). The obesity-associated mean RoM reductions for the left and right sides were 12.3% and 11.1%, respectively. None of the ankle joints motions showed statistically significant inter-group mean RoM differences (Table 8).

Table 5. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the elbow flexions.

	Elbow joint motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Left	Flexion	132.3 ± 7.1	128.5 ± 6.8	−2.9	0.0973
Right	Flexion	131.8 ± 6.8	129.3 ± 7.1	−1.9	0.2630

Note: No statistically significant difference found at Bonferroni-adjusted testwise α of 0.025 (=0.05/2).

Table 6. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the lumbar spine motions.

	Lumbar spine motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Unilateral	Flexion	58.1 ± 5.8	53.7 ± 8.8	−7.6	0.0696
	Extension	24 ± 4	18.8 ± 6.4	−21.7*	0.0041*
Left	Rotation	12.9 ± 3.4	12.7 ± 4.3	−1.6	0.9031
	Lateral flexion	35 ± 4.5	28 ± 5.6	−20*	0.0001*
Right	Rotation	13.3 ± 2.7	12.6 ± 4.3	−5.3	0.5691
	Lateral flexion	34.8 ± 4.2	28.4 ± 6.8	−18.4*	0.0009*

*Significantly different at Bonferroni-adjusted testwise α of 0.008333 (=0.05/6).

Table 7. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the knee flexions.

	Knee joint motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Left	Flexion	128.7 ± 10.2	112.9 ± 6.5	−12.3*	<0.0001*
Right	Flexion	129 ± 10.9	114.7 ± 8.1	−11.1*	<0.0001*

*Significantly different at Bonferroni-adjusted testwise α of 0.025 (=0.05/2).

Table 8. Group range of motion (RoM) means and standard deviations and inter-group mean RoM differences for the ankle joint motions.

	Ankle joint motion	Non-obese group (°)	Obese group (°)	Mean difference (obese − non-obese, %)	*p*-value
Left	Plantarflexion	31.7 ± 7.1	33.7 ± 8.6	6.3	0.4255
	Dorsiflexion	15.5 ± 2.9	16.4 ± 3.3	5.8	0.3672
Right	Plantarflexion	31.9 ± 7.6	33.8 ± 7.2	6.0	0.4106
	Dorsiflexion	15.3 ± 4.8	17.4 ± 3.6	13.7	0.1211

Note: No statistically significant difference found at Bonferroni-adjusted testwise α of 0.0125 (=0.05/4).

4. Discussion

This study investigated the obesity effect on male joint RoM based on data collected from a sample of 20 obese and 20 non-obese males. A total of 30 motions occurring at the cervical and lumbar spine areas and shoulder, elbow, knee and ankle joints were examined.

The obesity effect was found to vary across the body joint motions examined. Obesity significantly reduced RoM for only nine of the 30 motions examined: shoulder joint extensions and adductions, lumbar spine extension and lateral flexions and knee joint flexions (Tables 3–8). For the rest of motions, no significant obesity effect was found. The amount of RoM reduction varied across the nine motions for which a significant obesity effect was observed. When expressed as a percentage of the mean RoM of the non-obese group, the largest significant RoM reduction was 38.9 for the left shoulder adduction. The smallest was 11.1% for the right knee flexion.

It is thought that the observed RoM reductions are mainly due to the excess fat in the obese body. Such fat would interpose and mechanically obstruct intersegmental rotations at body joints (Laubuch 1969, Escalante *et al.* 1999a,b, Chaffin *et al.* 2006, Gilleard and Smith 2007). Aside from excess fat, reduced physical activity might also be hypothesised as a possible contributor to the observed RoM reductions as obesity is generally associated with a lower level of physical activity during daily life (Jebb and Moore 1999, Kaplan *et al.* 2003, Kvaaik *et al.* 2003, Yamakawa *et al.* 2004) and physical inactivity can decrease body flexibility (Kottke 1965, Buckwalter 1997). However, the current study did not allow testing of this physical inactivity hypothesis as the participants' physical activity levels were not recorded.

What gave rise to the non-uniformity of obesity effect across different body joint motions is not entirely clear. However, such motion-specific nature of obesity effect seems largely attributed to the body fat accumulation and distribution pattern of human obesity. When a person gains fat and becomes obese, fat is known to accumulate non-uniformly across different body regions (Arner 1997). In other words, in the human body, there are sites where fat deposits occur more easily than others. Some commonly used expressions, such as arm flab, love handles and potbelly, indeed refer to such fat deposit sites.

Logically, non-uniform fat distribution implies that the degree of mechanical interposition and obstruction by excess fat would vary across different body joint areas and motions; and thus, the obesity effect on RoM would be specific to each motion. The obesity-associated RoM reductions for shoulder extensions (Table 4) and lumbar lateral flexions (Table 6) seem to be direct results of the arm flab and love handle phenomena, respectively. The potbelly style fat deposit seems to be the main reason for the significant RoM reduction for the lumbar extension (Table 6). During the lumbar extension, the visceral fat in the abdomen area would increase the abdominal pressure, which interferes with the motion. The thigh areas, especially the back sides, are also known to easily deposit fat. It is thought to be the main reason for the obesity-associated RoM reductions for the knee flexions.

To some extent, the motion-specific nature of the obesity effect could be explained in relation to the human anatomical structure and how it constrains human motions. An example illustrating this is the significant obesity-associated RoM reductions for the shoulder adductions and the lack of such effect for the shoulder abductions (Table 4). When obese individuals perform shoulder adductions, the fat deposited in the chest and abdomen areas of the obese body obstructs the movements of the upper extremities. In contrast, during shoulder abductions, such obstruction does not occur because the upper extremities move away from the body and, thus, from the obstructing fat tissues in the chest and abdomen areas.

The motion-specific nature of obesity effect might also be related to the differences between joint motions in the frequency of occurrence during routine daily activities. As mentioned earlier, obesity was found to significantly reduce RoM for the shoulder extensions and adductions but not for the shoulder flexions and abductions (Table 4). Also, significant obesity-related RoM reductions were found for the lumbar extension and lateral flexions but not for the lumbar flexion and rotations (Table 6). In both cases, the latter appear to more frequently occur than the former in normal daily activities. From these observations, it may be hypothesised that frequent use of a joint motion mitigates obesity-associated RoM reduction. From an application point of view, this represents an interesting possibility for improving the body flexibility of obese individuals: regular exercises designed to promote motions that individuals do not frequently use in daily activities might help obese individuals regain body flexibility without having to lose significant body mass. The hypothesis is currently under investigation.

The obesity-associated RoM reductions may cause decreases in physical abilities to perform work and daily-life activities. The RoM reductions found for the shoulder extensions and adductions, lumbar spine extension and lateral flexions and knee flexions suggest that obese individuals are likely to have limited functional reach capabilities in both the standing and seated positions when compared with non-obese individuals. Related to this, Larsson and Mattsson (2001) have reported that obese individuals experience difficulties in performing reaches during activities of daily living, such as picking up coins on the floor and putting on socks. The current results warrant further studies for quantifying obese individuals' reach capabilities. A quantification of the reach capabilities of obese individuals will greatly facilitate inclusive design of products, workplaces and environments for obese individuals.

The obesity-associated RoM reductions also seem to have implications on human working postures and work-related biomechanical stresses. The human body is able to perform a manual task based on an infinite number of postures since it has a kinematically flexible structure with many body joint degrees of freedom. This is the so-called kinematic redundancy of the human body (Bernstein 1967). The obesity-associated RoM reductions essentially amount to a reduction in the kinematic redundancy; that is, when planning a working posture for a given manual task, an obese worker has a smaller range of feasible body postures to select from than a non-obese individual. For example, in performing certain low-lying object lifting tasks, severely obese individuals may find it difficult or impossible to utilise squat lifting postures due to reduced knee joint flexion RoM. A reduction in the kinematic redundancy would hamper exploring and utilising biomechanically advantageous postures for manual tasks and, therefore, make it difficult to control work-related biomechanical stresses. Thus, it would likely lead to increased biomechanical stresses. Indeed, Gilleard and Smith (2007) showed that obese and non-obese individuals adopt different work postures during a standing grasp task and the postures adopted by obese workers were biomechanically more disadvantageous compared with those used by the non-obese. When combined with larger body masses, such biomechanically disadvantageous postures would severely aggravate work-related physical stresses for obese individuals (Gilleard and Smith 2007).

Some limitations of the current study are described here alongside future research directions. First, although the sample size in this study allowed statistical testing and characterisation of the obesity effect on male RoM, it was not large enough to generate accurate point estimates of the population parameters. Thus, the descriptive statistics provided in Tables 3–8 should not be regarded as clinical normative RoM data for the obese. Second, the obese group in the present study represented the extremely obese category (mean BMI > 40 kg/m^2) among a number of different obesity categories. In future studies, other obesity categories, such as overweight and moderately obese groups, should be considered to provide a more complete understanding of the obesity effect. Third, the current study collected only male participants' RoM data. Further research is needed to characterise the obesity effect on female RoM. Since gender is known to affect the fat distribution pattern of obesity (Arner 1997), the obesity effect on female RoM may differ from that on male RoM.

Acknowledgement

The authors would like to thank Hanna Lee for her help during the preparation of the manuscript.

References

Alter, M.J., 1996. *Science of flexibility*. Champaign, IL: Human Kinetics.

American Academy of Orthopedic Surgeons, 1965. *Joint motion; method of measuring and recording*. Chicago, IL: American Academy of Orthopedic Surgeons.

American Medical Association, 1993. *Guides to the evaluation of permanent impairment*. 4th ed. Chicago, IL: American Medical Association.

Arner, P., 1997. Regional adiposity in man. *Journal of Endocrinology*, 155 (2), 191–192.

Badley, E.M., Wagstaff, S., and Wood, P.H.N., 1984. Measures of functional ability (disability) in arthritis in relation to impairment of joint motion. *Annals of Rheumatic Diseases*, 43, 563–569.

Baskin, M.L., *et al*., 2005. Prevalence of obesity in the United States. *Obesity Reviews*, 6, 5–7.

Bernstein, N., 1967. *The coordination and regulation of movements*. New York: Pergamon.

Buckwalter, J.A., 1997. Decreased mobility in the elderly: the exercise antidote. *Physical and Sports Medicine*, 25, 126–133.

Chaffin, D.B., Anderson, G.B.J., and Martin, B.J., 2006. *Occupational biomechanics*. 4th ed. New York: John Wiley and Sons, Inc.

Doriot, N. and Wang, X., 2006. Effects of age and gender on maximum voluntary range of motion of the upper body joints. *Ergonomics*, 49, 269–281.

Escalante, A., Lichtenstein, M.J., and Hazuda, H.P., 1999a. Determinants of shoulder and elbow flexion range: results from the San Antonio longitudinal study of aging. *The American College of Rheumatology*, 12 (4), 277–286.

Escalante, A., *et al*., 1999b. Determinants of hip and knee flexion range: results from the San Antonio longitudinal study of aging. *The American College of Rheumatology*, 12 (1), 8–18.

Feipel, V., *et al*., 1999. Normal global motion of the cervical spine: an electrogoniometric study. *Clinical Biomechanics*, 14, 462–470.

Ferrario, V.F., *et al*., 2002. Active range of motion of head and cervical spine: a three-dimensional investigation in healthy young adults. *Journal of Orthopaedic Research*, 20, 122–129.

Flegal, K.M., *et al*., 2002. Prevalence and trends in obesity among US adults, 1999–2000. *Journal of the American Medical Association*, 288, 1723–1727.

Gilleard, W. and Smith, T., 2007. Effect of obesity on posture and hip joint moments during a standing task, and trunk forward flexion motion. *International Journal of Obesity*, 31 (2), 267–271.

Hertz, R.P., *et al.*, 2004. The impact of obesity on work limitations and cardiovascular risk factors in the U.S. workforce. *Journal of Occupational and Environmental Medicine*, 46 (12), 1196–1203.

Hu, H., *et al.*, 2006. Measurements of voluntary joint range of motion of the Chinese elderly living in Beijing area by a photographic method. *International Journal of Industrial Ergonomics*, 36, 861–867.

Jebb, S.A. and Moore, M.S., 1999. Contribution of a sedentary lifestyle and inactivity to the etiology of overweight and obesity: current evidence and research issues. *Medicine and Science in Sports and Exercise*, 31, S534–S541.

Kaplan, M.S., *et al.*, 2003. Prevalence and correlates of overweight and obesity among older adults: findings from the Canadian National Population Health Survey. *Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 58, 1018–1030.

Kee, D. and Karwowski, W., 2002. Analytically derived three-dimensional reach volumes based on multijoint movements. *Human Factors*, 44, 530–544.

Kottke, F.J., 1965. Deterioration of the bedfast patient, causes and effects. *Public Health Reports*, 80, 437–451.

Kuhlman, K.A., 1993. Cervical range of motion in the elderly. *Archives of Physical Medicine and Rehabilitation*, 74, 1071–1079.

Kvaaik, E., Tell, G.S., and Klepp, K.I., 2003. Predictors and tracking of body mass index from adolescence into adulthood: follow-up of 18–20 years in the Oslo Youth Study. *Archives of Pediatrics and Adolescent Medicine*, 157, 1212–1218.

Larsson, U.E. and Mattsson, E., 2001. Functional limitation linked to high body mass index, age and current pain in obese women. *International Journal of Obesity*, 25, 893–899.

Laubuch, L.L., 1969. Body composition in relation to muscle strength and range of motion. *Sports Medicine and Physical Fitness*, 9 (5), 89–97.

McGill, S.M., Yingling, V.R., and Peach, J.P., 1998. Three-dimensional kinematics and trunk muscle myoelectric activity. *Clinical Biomechanics*, 14, 389–395.

Mokdad, A.H., *et al.*, 1999. The spread of the obesity epidemic in the United States, 1991–1998. *Journal of the American Medical Association*, 282, 1519–1522.

Murray, M.P., *et al.*, 1985. Shoulder motion and muscle strength of normal men and women in two age groups. *Clinical Orthopedics*, 198, 268–273.

Reese, N.B. and Bandy, W.D., 2002. *Joint range of motion and muscle length testing*. Philadelphia, PA: W.B. Sanders Company.

Sforza, C., *et al.*, 2002. Three-dimensional analysis of active head and cervical spine range of motion: effect of age in healthy male subjects. *Clinical Biomechanics*, 17 (8), 611–614.

Stubbs, N.B., Fernandez, J.E., and Glenn, W.M., 1993. Normative data on joint ranges of motion of 25- to 54-year-old males. *International Journal of Industrial Ergonomics*, 12, 265–272.

Torén, A., 2001. Muscle activity and range of motion during active trunk rotation in a sitting posture. *Applied Ergonomics*, 32 (6), 583–591.

Verbrugge, L.M. and Jette, A.M., 1994. The disablement process in the elderly spine: a database compared to young people. *Social Science and Medicine*, 38, 1–14.

Yamakawa, K., *et al.*, 2004. Relationship between ambulation and obesity in older persons with and without low back pain. *International Journal of Obesity and Related Metabolic Disorders: Journal of the International Association for the Study of Obesity*, 28, 137–143.

Zhang, X., *et al.*, 2005. A normative database of thumb circumduction in vivo: center of rotation and range of motion. *Human Factors*, 47 (3), 550–561.