Thoracic and Lumbar Spine Accelerations in Everyday Activities

Tracy P. Ng, William R. Bussone, Stefan M. Duma
Virginia Tech – Wake Forest Center for Injury Biomechanics
Blacksburg, VA

Tyler A. Kress
University of Tennessee Safety Center
Knoxville, TN

ABSTRACT

The purpose of this study was to quantify thoracic and lumbar spine accelerations for men and women of different body sizes during daily activities. Measured spine accelerations were compared to determine if there were significant differences in peak accelerations based on gender, size, and spine location. Each subject performed seven activities, which included sitting in a chair, sitting quickly in a chair, walking at 1.3 m/s, running at 2.7 m/s, performing jumping jacks, achieving maximum vertical leap, and jumping off a step approximately 20 cm high. Overall, the peak lumbar spine accelerations were significantly greater than the thoracic spine accelerations. Based on the statistical analysis, it was determined that gender and body size did not have a significant effect on peak accelerations of the thoracic and lumbar spine. The findings from the present study are of great value to researchers in order to understand the acceleration patterns of the human body during low impact accelerations.

Keywords: spine, thoracic, lumbar, acceleration, size, gender, daily activities

INTRODUCTION

For over 40 years, researchers and engineers have been quantifying the acceleration of the human body in order to understand the injury response of the body in different loading scenarios. Despite the large amount of experimental data regarding the acceleration patterns of the human body, few studies have focused on quantifying human body accelerations during daily activities.

Allen measured accelerations of the human head during daily perturbations using three helmet mounted accelerometers and compared his results to low velocity rear-end motor vehicle accidents [1]. Menz used tri-axial accelerometers to measure accelerations of the head and sacrum during self-selected walking speeds and reported peak accelerations of 0.75 g and 0.5 g at the pelvis and head, respectively [2]. Differences between head and trunk accelerations for young and elderly men were investigated by Kavanagh who found that elderly subjects exhibited different patterns of upper body motion compared to younger subjects [3]. Other studies have determined gait parameters by using accelerometers secured to subjects at the L3 and S2 vertebrae [4],[5].

No literature to date has investigated the effect of subject size and gender on peak accelerations of the thoracic and lumbar regions of the human body during everyday activities. The purpose of this study is to quantify the acceleration of the thoracic and lumbar spine during daily activities and determine if significant differences exist between the peak accelerations of men and women of different body sizes.

METHODS

A total of 18 healthy volunteer subjects were used for the experimental tests and asked to perform seven daily activities. The activities included sitting in a chair normally and quickly, walking at 1.3 m/s, running at 2.7 m/s, performing jumping jacks, achieving maximum vertical leap, and jumping off a step approximately 20 cm high. All subjects read and signed an informed consent form and had the opportunity to withdraw from any or all parts of the testing at any time. All test procedures were reviewed and approved by the Virginia Tech Institutional Review Board. The subjects were organized according to height and weight into one of four size groups (small female, mid-female, mid-male, and large male), with each group corresponding to an anthropometric target size (Hybrid III 5th and 50th female, Hybrid III 50th and 95th male).

Each subject was instrumented with three linear accelerometers (Endevco 7596A, 30 G, San Juan Capistrano, CA) mounted posterior to the T1 and L5 vertebrae, as shown in Figure 1. The accelerometers were secured directly onto the skin posterior using adhesive tape, while foam padding wrapped with an elastic bandage was used to hold the arrays in the proper position.

a. b. c.

Figure 1. Orientation of the accelerometers at the T1 and L5 vertebrae (a), mounted posterior using adhesive tape (b), and secured with foam padding wrapped with an elastic bandage (c).

Data from the accelerometers and rate sensors were recorded at a sampling frequency of 2,000 Hz using an Iotech Wavebook with WBK16 strain gage modules (Iotech WBK16, Cleveland, OH). A sampling frequency of 2,000 Hz was chosen based on the low impact accelerations that were being measured. Data were post-processed in MATLAB (The MathWorks MATLAB 7.0.1, Natick, MA) to calculate the resultant and peak linear accelerations for each subject during each activity. All data were normalized with acceleration due to gravity and analyzed using a standard unit of g.

Statistical analysis was performed using a two sample t-test assuming unequal variances to determine if there were significant differences in peak accelerations among subjects due to variables such as gender and body size. It was also determined if there were significant differences between accelerations at the thoracic and lumbar spine. Variables with p-values of 0.05 or less were considered significant.

RESULTS

A total of four subjects were categorized as small females, five as mid-females, five as mid-males, and four as large males. The average height and weight for each size group are listed in Table 1, along with the standard deviation values. All 18 subjects completed each activity with no complaints regarding injury or discomfort. Peak resultant accelerations measured at the T1 and L5 vertebrae for each subject and activity are listed in Table 2 and Table 3. Bar charts of the average peak resultant accelerations for each size group measured at the upper and lower spine for all seven activities are shown in Figure 2 and Figure 3.

Table 1. Average height and weight for each size group.

	Height (m)	Weight (kg)
Small Female	1.58 ± 0.04	53.64 ± 2.45
Mid Female	1.65 ± 0.04	63.88 ± 3.14
Mid Male	1.74 ± 0.03	76.48 ± 2.92
Large Male	1.82 ± 0.06	92.83 ± 3.02

Table 2. Peak resultant accelerations and averages (g) at the T1 vertebrae.

	Subject Number	Sit in chair	Sit quickly in chair	Walk (1.3 m/s)	Run (2.7 m/s)	Jumping jacks	Vertical leap	Jump off step
Small Female	SF1	1.18	1.24	0.57	3.00	5.07	3.91	4.51
	SF2	1.27	5.14	0.59	2.01	3.95	2.95	2.40
	SF3	0.55	4.03	0.67	1.56	3.63	8.26	4.19
	SF4	0.81	3.35	0.61	2.56	4.15	3.06	2.32
	Average	0.95	3.44	0.61	2.28	4.20	4.54	3.36
	Std Dev	0.34	1.65	0.04	0.63	0.62	2.51	1.16
Mid Female	MF1	0.74	2.80	0.71	2.27	3.46	11.36	4.05
	MF2	0.84	1.29	0.76	1.95	3.51	3.40	6.25
	MF3	1.47	6.46	1.09	2.91	4.70	3.39	2.88
	MF4	1.24	3.02	0.56	1.98	3.03	10.02	4.15
	MF5	1.46	3.80	0.65	2.00	3.83	4.29	3.04
	Average	1.15	3.47	0.76	2.22	3.71	6.49	4.07
	Std Dev	0.35	1.90	0.20	0.41	0.62	3.88	1.34
Mid Male	MM1	0.65	2.92	0.54	2.53	3.23	6.97	5.04
	MM2	1.09	2.99	0.54	1.50	5.06	5.60	7.93
	MM3	1.14	2.77	0.53	2.44	5.28	7.82	7.79
	MM4	1.42	2.52	0.58	2.33	4.28	10.61	4.09
	MM5	1.13	3.95	0.78	2.50	3.00	5.94	2.65
	Average	1.09	3.03	0.60	2.26	4.17	7.39	5.50
	Std Dev	0.28	0.54	0.11	0.43	1.04	2.00	2.31
Large Male	LM1	1.25	1.80	0.48	1.84	3.69	5.09	3.99
	LM2	1.72	3.59	0.69	2.26	3.25	8.42	2.67
	LM3	1.76	2.07	0.70	1.91	2.87	2.47	3.37
	LM4	1.19	1.51	0.80	1.49	3.13	3.81	3.10
	Average	1.48	2.24	0.67	1.88	3.24	4.95	3.28
	Std Dev	0.30	0.92	0.13	0.31	0.34	2.55	0.55
Overall	Average	1.16	3.07	0.66	2.17	3.84	5.97	4.14
	Std Dev	0.34	1.34	0.14	0.44	0.77	2.85	1.68

Table 3. Peak resultant accelerations and averages (g) at the L5 vertebrae.

	Subject Number	Sit in chair	Sit quickly in chair	Walk (1.3 m/s)	Run (2.7 m/s)	Jumping jacks	Vertical leap	Jump off step
Small Female	SF1	1.71	1.23	0.82	3.92	9.29	6.03	7.18
	SF2	0.94	7.10	0.86	2.82	6.11	4.92	3.94
	SF3	0.50	7.26	0.87	2.40	9.89	9.91	5.87
	SF4	0.75	4.77	0.95	3.43	4.97	3.77	3.54
	Average	0.98	5.09	0.87	3.14	7.56	6.16	5.13
	Std Dev	0.52	2.81	0.05	0.67	2.40	2.67	1.70
Mid Female	MF1	0.60	3.07	0.94	2.19	7.82	13.28	5.03
	MF2	1.20	2.43	1.47	5.22	8.30	7.80	12.46
	MF3	1.73	7.58	1.34	3.23	5.47	6.28	4.24
	MF4	1.48	3.36	0.95	3.70	4.44	10.94	9.52
	MF5	1.71	4.75	1.02	3.30	8.22	5.60	6.35
	Average	1.34	4.24	1.14	3.53	6.85	8.78	7.52
	Std Dev	0.47	2.05	0.24	1.10	1.78	3.25	3.42
Mid Male	MM1	0.89	2.67	0.83	4.00	6.58	9.13	6.38
	MM2	0.59	4.51	0.81	2.13	6.48	8.58	7.64
	MM3	0.71	3.96	0.86	4.57	11.61	13.12	8.84
	MM4	1.12	5.09	0.73	4.16	6.34	11.84	8.06
	MM5	0.68	5.72	1.14	4.33	9.85	14.56	5.90
	Average	0.80	4.39	0.88	3.84	8.17	11.45	7.37
	Std Dev	0.21	1.16	0.16	0.98	2.42	2.56	1.21
Large Male	LM1	1.34	2.29	0.92	4.50	10.61	11.23	11.23
	LM2	1.18	5.69	0.87	5.08	6.69	21.47	9.14
	LM3	1.21	5.46	0.92	4.96	5.18	6.36	6.87
	LM4	0.78	2.26	1.12	3.31	4.63	6.03	4.99
	Average	1.13	3.93	0.96	4.46	6.78	11.27	8.06
	Std Dev	0.24	1.91	0.11	0.81	2.70	7.20	2.71
Overall	Average	1.06	4.40	0.97	3.74	7.36	9.49	7.07
	Std Dev	0.41	1.88	0.19	0.96	2.19	4.37	2.47

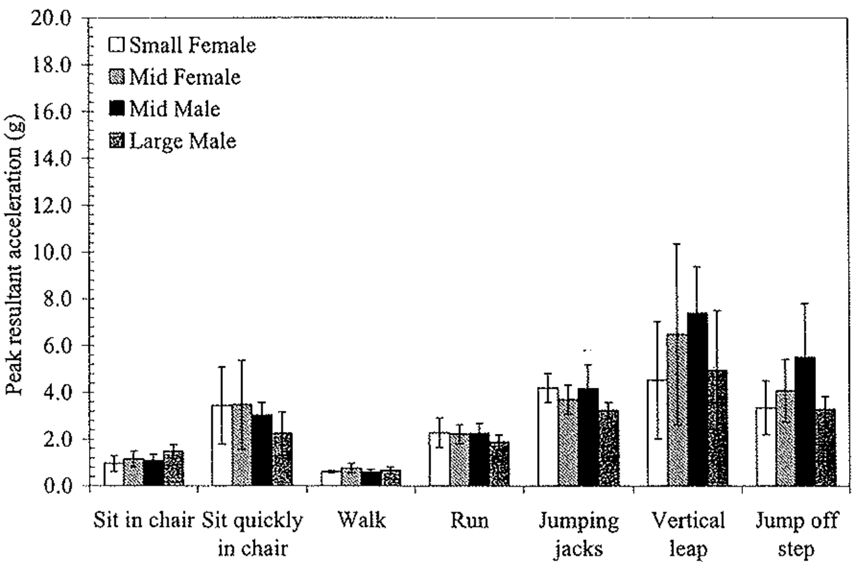

Figure 2. Average peak resultant accelerations and standard deviation error bars at the T1 vertebrae for each activity and size group.

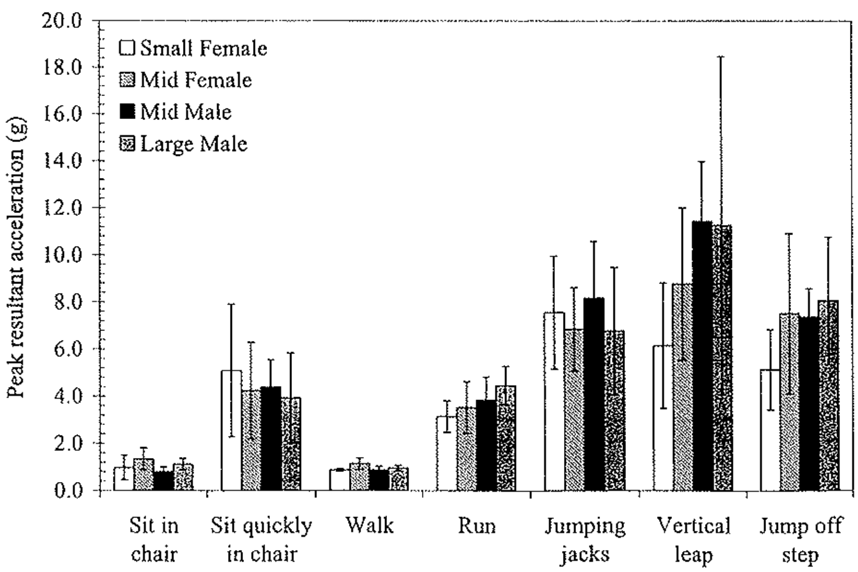

Figure 3. Average peak resultant accelerations and standard deviation error bars at the L5 vertebrae for each activity and size group.

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[3] J.J. Kavanagh, R.S. Barrett,
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[4] R. Moe-Nilssen and J.L. He
pp. 121-126, Jan 2004.
[5] W. Zijlstra and A.L. Hof, "A
Gait Posture, vol. 18(2), pp.

In general, higher peak accelerations were measured during the jumping activities, while lower to moderate accelerations occurred during the sitting, walking, and running events. It was determined that there was a significant difference between accelerations at the T1 and L5 vertebrae, therefore the effects of gender and size on peak accelerations were analyzed separately for each spine location and activity. Based on the statistical analysis, it was found there was no significant difference between peak accelerations due to gender and body size. At the T1 location, only 15.38% and 17.95% of the tests were significantly different based on gender and size, respectively. Similarly, at the L5 vertebrae, 15.38% and 12.82% of the tests were significantly different based on gender and size, respectively.

DISCUSSION

Trunk accelerations during walking from previous studies agree well with the measured acceleration from the current study. Zijlstra, Kavanagh, and Menz quantified accelerations of the pelvis during walking [2],[3],[5]. Although peak lumbar accelerations from this study are in close agreement with accelerations reported by [3] and [5], they are slightly higher than the accelerations from [2]. Differences between the results from the current study and [2] may be attributed to different walking speeds. In the current study, subjects performed the walking activity on a treadmill at a uniform speed of 1.3 m/s, while subjects in [2] were instructed to walk at a self prescribed walking speed.

As expected, the peak accelerations were significantly different between the thoracic and lumbar spine regions. In general, the thoracic spine accelerations were lower than the lumbar spine accelerations. This finding agrees with previous studies and illustrates the force attenuation capability of the spine [2]. The spine also exhibited a delay in transferring the initial contact force from the lumbar spine to the thoracic spine.

The findings from the current study suggest that gender and size do not have a statistically significant effect on peak accelerations of the thoracic and lumbar spine. Since there have been no previous studies to the authors' knowledge that investigate the effect of gender and body size on thoracic and lumbar spine accelerations measured simultaneously, this is the first study to determine this finding.

CONCLUSIONS

In the current study, thoracic and lumbar spine accelerations were measured for 18 volunteers during seven daily activities. Peak accelerations were compared to determine if there were significant differences based on variables such as gender and body size. Higher peak accelerations were recorded during the jumping activities, while lower accelerations occurred during the sitting, walking and running events. There were significant differences in peak accelerations between the T1 and L5 vertebrae, with higher accelerations in the lumbar region. It was determined that gender and body size do not have a statistically significant effect on peak accelerations at the T1 and L5 vertebrae.

REFERENCES

[1] M.E. Allen, I. Weir-Jones, D.R. Motiuk, K.R. Flewin, R.D. Goring, R. Kobetitch, and A. Broadhurst, "Acceleration perturbations of daily living: a comparison to whiplash," *Spine*, vol. 19(11), pp. 1285-90, June 1994.

[2] H.B. Menz, S.R. Lord, and R.C. Fitzpatrick, "Acceleration patterns of the head and pelvis when walking on level and irregular surfaces," *Gait Posture*, vol. 18(1), pp. 35-46, Aug 2003.

[3] J.J. Kavanagh, R.S. Barrett, and S. Morrison, "Upper body accelerations during walking in healthy young and elderly men," *Gait Posture*, vol. 20(3), pp. 291-98, Dec 2004.

[4] R. Moe-Nilssen and J.L. Helbostad, "Estimation of gait cycle characteristics by trunk accelerometry," *J Biomech*, vol. 37(1), pp. 121-126, Jan 2004.

[5] W. Zijlstra and A.L. Hof, "Assessment of spatio-temporal gait parameters from trunk accelerations during human walking," *Gait Posture*, vol. 18(2), pp. 1-10, Oct 2003.

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