The Effect of Gender and Body Size on Linear Accelerations of the Head Observed During Daily Activities

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ABSTRACT

The purpose of this study was to determine the effect of gender and body size on peak linear head accelerations during daily activities. Head accelerations were measured for 18 volunteers using a biteplate system. Each subject performed seven activities: sitting in a chair, sitting quickly in a chair, walking at 1.3 m/s, running at 2.7 m/s, performing jumping jacks, doing a vertical leap, and jumping off a step approximately 20 cm high. Peak resultant head accelerations for each subject and activity were compared to determine if there were statistically significant differences based on variables such as gender and size. All measured accelerations were below 10 g with a maximum peak acceleration of 9.54 g recorded during the vertical leap activity. Larger head accelerations were measured during the jumping activities, while lower accelerations occurred during the sitting, walking, and running events. Based on the statistical analysis, it was determined that gender and size do not have a statistically significant effect on peak linear accelerations of the head during daily activities.

Keywords: head, linear, acceleration, daily activities, gender, size

INTRODUCTION

Since the 1960s, researchers and engineers have been quantifying the acceleration of the human body in order to understand the injuries that may result from different acceleration environments. To date, most of the studies have focused on measuring human body accelerations in the 20-40 g acceleration range, simulating automobile collisions or airplane take-off and landing scenarios [1]-[3]. In contrast, few studies have concentrated on quantifying the acceleration of the human body in response to everyday activities in the 1-10 g acceleration range.

Initial research to study the injury response of the human head in high impact loading conditions was conducted in the 1960s at NASA and Wayne State University [1]-[3]. More recent studies have quantified acceleration patterns of the human body during less severe loading scenarios. 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 [4]. In contrast, 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 [5]. Similarly, Mercer investigated characteristics of shock attenuation during fatigued running and recorded peak head accelerations of 1.5 g at a running speed of 3.5 m/s [6]. Other studies have examined the acceleration of the head and trunk under normal walking and running conditions to determine gait parameters [7]-[9].

No literature to date has investigated the effect of subject body size and gender on peak linear accelerations of the head during everyday activities. It is the purpose of this study to quantify the acceleration of the head during daily activities and determine whether significant differences exist between the peak head accelerations of men and women of different body sizes.

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METHODS

Volunteer subjects for the tests were asked to perform seven activities: sitting in a chair normally and quickly, walking at 1.3 m/s, running at 2.7 m/s, performing jumping jacks, doing a 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 a biteplate system that was used to measure the linear acceleration of the head. The biteplate consisted of a custom aluminum plate screwed to the drilled flange of a stainless steel dental impression tray. Three linear accelerometers (Endevco 7596A, 30 G, San Juan Capistrano, CA) with a resolution of 0.008 G were mounted in a tri-axial configuration on a 1 inch Delrin block, which was then screwed to the bottom of the mouthpiece. The weight of the biteplate mounted on a medium sized impression tray was 240 g.

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 measured accelerations were normalized with acceleration due to gravity and are reported in units of g. Dynamic equations of motion were solved to resolve the accelerations from the mouthpiece to the center of gravity of the head for each subject. The line of the mouthpiece and the mouthpiece angle relative to the Frankfort plane, shown in Figure 1, were taken into account for each subject while resolving the mouthpiece accelerations to the center of gravity.

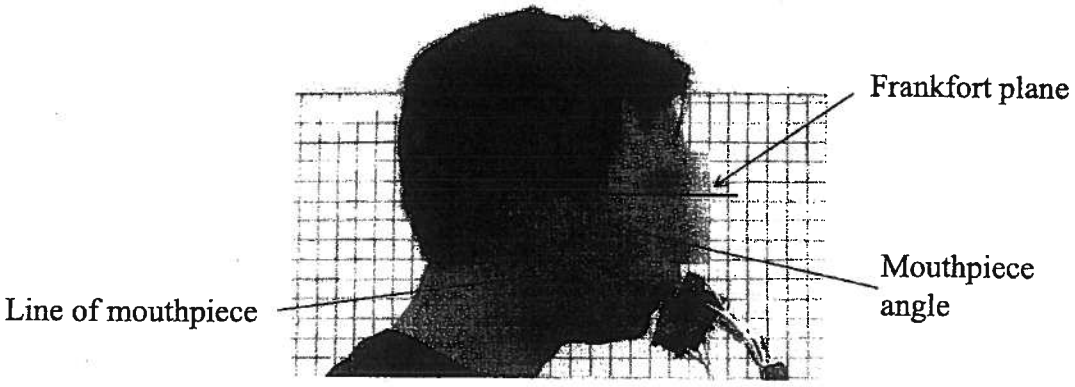

Figure 1. Position of the mouthpiece relative to the Frankfort plane.

Statistical analysis was performed using a two sample t-test assuming unequal variances. Evaluated were significant differences in peak acceleration due to variables such as activity, size, and gender. Variables with p-values of 0.05 or less were considered significant.

RESULTS

Eighteen healthy volunteer subjects were used for this study with four subjects categorized as small females, five as mid-females, five as mid-males, and four as large males. The average weight and height for each size group are listed in Table 1, along with standard deviation values. Subjects ranged in age from 19-32 years of age. All 18 subjects completed each activity with no complaints regarding injury or discomfort. Peak resultant accelerations for each subject and activity are listed in Table 1, in addition to average and standard deviation values for each size group. A bar chart with average peak accelerations for each size group and activity is shown in Figure 2.

Table 1. Linear peak resultant head accelerations and averages (g) for each subject.

	Subject Number	Height (m)	Weight (kg)	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	1.57	54.25	1.28	1.19	0.55	1.90	3.28	2.79	3.78
	SF2	1.63	50.62	0.64	3.43	0.70	2.09	3.29	2.72	2.40
	SF3	1.52	53.16	0.60	3.70	0.92	1.60	3.87	3.55	4.05
	SF4	1.59	56.52	0.43	2.83	0.68	1.66	2.96	2.49	2.00
	Average	1.58	53.64	0.74	2.79	0.71	1.81	3.35	2.89	3.06
	Std Dev	0.04	2.45	0.37	1.12	0.15	0.23	0.38	0.46	1.01
Mid Female	MF1	1.60	60.06	0.56	2.73	0.70	1.34	3.64	8.08	2.60
	MF2	1.62	68.04	0.88	1.73	0.73	2.38	3.17	2.82	3.47
	MF3	1.68	65.50	1.34	4.01	1.02	1.44	2.70	2.56	2.77
	MF4	1.68	61.69	1.29	2.43	0.67	1.67	3.15	4.89	3.44
	MF5	1.70	64.14	1.29	2.63	0.67	1.80	3.21	3.58	2.05
	Average	1.65	63.88	1.07	2.71	0.76	1.73	3.17	4.39	2.87
	Std Dev	0.04	3.14	0.34	0.83	0.15	0.41	0.33	2.26	0.60
Mid Male	MM1	1.71	77.56	0.58	2.34	0.69	1.65	2.92	7.21	4.60
	MM2	1.74	72.21	0.75	2.30	0.51	1.42	4.19	5.02	4.62
	MM3	1.76	76.11	0.75	2.05	0.87	1.50	4.42	6.16	5.02
	MM4	1.73	80.29	1.54	1.79	0.74	2.63	4.04	6.75	3.58
	MM5	1.78	76.20	0.93	2.80	0.85	1.73	2.72	4.20	2.04
	Average	1.74	76.48	0.91	2.25	0.73	1.79	3.66	5.87	3.97
	Std Dev	0.03	2.92	0.37	0.38	0.14	0.49	0.78	1.24	1.20
Large Male	LM1	1.86	95.80	0.84	1.70	0.53	1.51	3.31	6.80	3.48
	LM2	1.75	93.71	1.42	2.13	0.68	1.42	2.79	9.54	3.34
	LM3	1.87	88.63	1.18	1.89	0.72	1.32	2.52	2.99	3.45
	LM4	1.78	93.17	0.68	1.09	0.63	1.62	2.42	3.37	2.77
	Average	1.82	92.83	1.03	1.70	0.64	1.47	2.76	5.68	3.26
	Std Dev	0.06	3.02	0.33	0.45	0.08	0.13	0.40	3.09	0.33
Overall	Average	1.70	71.54	0.94	2.38	0.71	1.70	3.26	4.75	3.30
	Std Dev	0.10	14.61	0.35	0.80	0.13	0.35	0.58	2.17	0.91

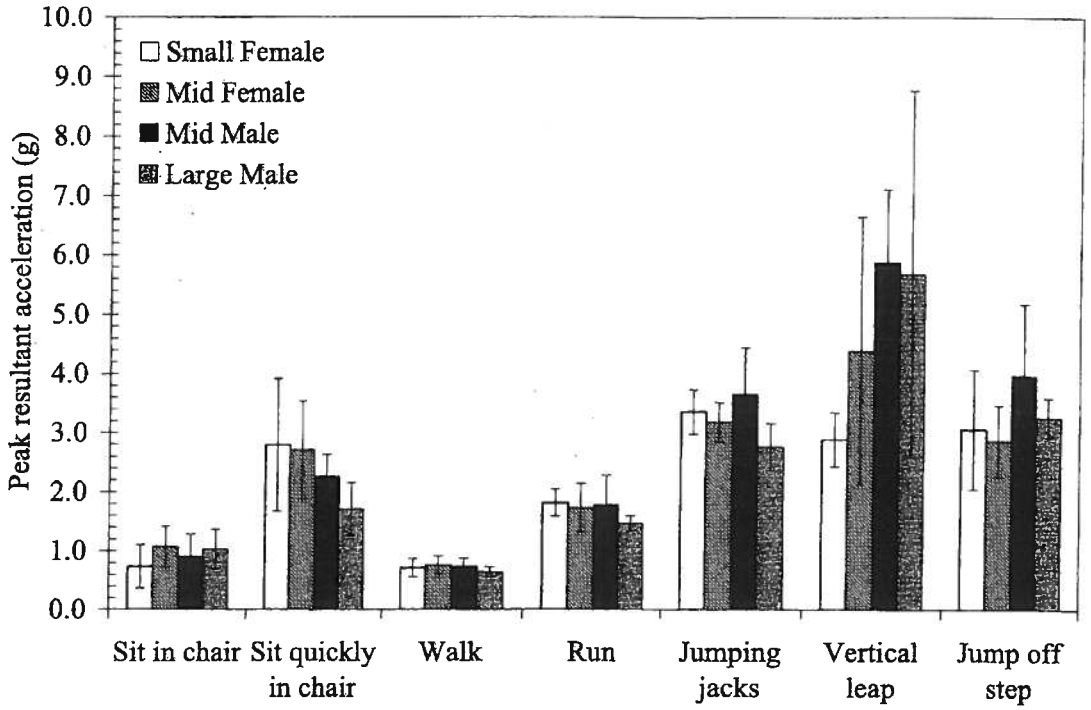

Figure 2. Average linear peak resultant accelerations and standard deviation error bars for each activity and size group.

All measured accelerations occurred below 10 g, with a maximum peak resultant acceleration of 9.54 g recorded during the vertical leap activity. Higher accelerations were recording in the jumping activities such as jumping jacks, vertical leap, and jumping off a step. Sitting normally in a chair and walking recorded lower accelerations, while sitting quickly in a chair produced moderate accelerations.

It was found that 95.24% of the peak accelerations were significantly different for each activity. Based on the dependence of peak acceleration on the specific activity, each activity was analyzed separately to evaluate the effect size and gender on head accelerations. Size was found to have an insignificant effect on peak accelerations with only 7.69% of the t-tests resulting in p-values of 0.05 or less. Similarly, only 15.38% of the t-tests comparing gender to peak acceleration were found to be significant.

DISCUSSION

The reported peak resultant linear accelerations agree well with previous studies [4]. Overall, the accelerations from Allen's daily head acceleration study were slightly higher for the sit down, sit down quickly, and jump-off-step events. Discrepancies between the two sets of reported values may be attributed to different accelerometer locations. Allen's measurements were taken from accelerometers mounted on the exterior of helmets and were not resolved to the center of gravity of the head. Peak resultant accelerations from this study were measured from accelerometers mounted on a mouthpiece and then resolved to the center of gravity of the head.

Results from previous studies that examined head accelerations during walking and running activities agree very well with the findings from this study [5]-[7],[9]. Kavanagh and Menz studied head accelerations during walking for healthy young and elderly men. Results from this study were almost identical to those reported by Menz, but slightly higher than those reported by Kavanagh, which may be due to different accelerometer positions. Both Mercer and Mahar measured linear accelerations during running from accelerometers mounted on the forehead. Accelerations measured during this study were similar to those reported by Mercer and slightly higher than those reported by Mahar. Differences between accelerations measured by Mahar and this study are likely due to a lack of uniform running speed for subjects in Mahar's study. In the current study, all subjects performed the running activity on a treadmill at 2.7 m/s, whereas Mahar's subjects ran at a self prescribed pace that was comparable to their own training pace.

Although the head undergoes both linear and rotational motion, most studies to date have considered the effects of linear motion only on the overall acceleration of the head [5]-[7],[9]. Even though this study focused on linear accelerations of the head, it is likely that including the angular acceleration of the head would result in a slight deviation of approximately 1 or 2 g from the peak accelerations reported in this study. In terms of daily head accelerations, which are generally well below 10 g, including the angular acceleration of the head could have significant effects on the overall head acceleration. The authors are currently investigating the effects of angular terms on the overall acceleration of the head during everyday activities.

The findings from the current study indicate that body size and gender have a statistically insignificant effect on linear accelerations of the head. Since there have been no previous studies that investigate the effect of size and gender on head accelerations, this is the first study to the authors' knowledge to determine this finding. It is possible that the statistically insignificant effect of gender and body size on linear accelerations of the head may be due to the relatively small sample size for each size group. Four subjects were categorized as small female and large male, while five subjects were considered mid-female and mid-male. Larger sample sizes may provide a better understanding of the effect of gender and body size on linear accelerations of the head during low impact activities.

CONCLUSIONS

In this study, accelerations of the head were measured for 18 volunteers during daily activities, such as sitting, walking, and jumping. The peak resultant linear head accelerations for each subject were compared to determine if there were significant differences based on variables such as gender and body size. Results obtained from the experimental testing indicate that higher peak head accelerations occur during jumping activities such as jumping jacks, vertical leap, and jumping off a step. Lower head accelerations were recorded during the sitting, walking, and running activities. Based on the statistical analysis, it was determined that body size and gender do not have a significant effect on peak linear accelerations of the head. Only 15.38% of the t-tests comparing gender to peak acceleration were considered significant with p-values less than 0.05, while only 7.69% of the t-tests based on size were found to be significant. The findings from this study help to develop a better understanding of linear head accelerations during low impact activities.

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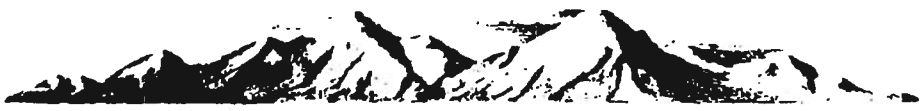

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