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Head and Low Back Human Activity Peak Acceleration Analysis Considerations

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Abstract: Head and low back peak accelerations occur throughout the course of daily living. In this study, activities such as walking, jogging, jumping, ascending/descending stairs, hopping down from an elevated surface, sitting down, and riding in a vehicle were studied and their corresponding head and low back accelerations were measured. To date, no study has examined, in detail, the complexity of peak accelerations of typical human activities. The collected acceleration data was analyzed for occurrences of peaks. Peaks were determined in each individual axis, and as a vector sum. The point in time between the vector sum peaks and the individual axis peaks were compared. The magnitude and direction of the head and low back vector sum peak accelerations were determined and compared. The magnitude and direction of the peak acceleration was examined and qualitatively assessed for its representativeness of the human activity. The use of data smoothing of the acceleration traces was demonstrated. These peak acceleration analysis consideration results were discussed for their impact on their interpretations to the measured human activities.

Keywords: Peak Acceleration, Human Activity, Analysis

1. Introduction

Measurement of physical human activity has long been a scientific effort in the fields of kinesiology, biomechanics and ergonomics. These efforts have multiple goals, such as, defining human limitations, development of population metrics, and supporting the development of guidelines and design parameters. While there are numerous types of physical human activity measurements, this paper examines the measurement of peak accelerations during human physical activity, pragmatically of activities that humans may typically do. Grieser et al. (2013), Larson et al. (2001) and Allen et al. (1994) have reported various peak accelerations associated with typical human activities. These publications provide head and low back peak accelerations in a single axis. The data collection and analysis methods employed by these authors provided the foundation for further, detailed evaluation of peak accelerations of typical human activities.

Thus, in this paper, the purpose was to examine peak acceleration analysis in more detail by: (1) analyzing peak accelerations in three dimensional space, (2) analyzing the specific timing of individual axis peaks versus vector sum peak accelerations, (3) analyzing the magnitude and direction of head versus low back peak accelerations, and (4) analyzing the potential excitation, independent of human activity movement, of the accelerometer at the point of the peak acceleration.

2. Methods

To record accelerations of activities, 10G triaxial accelerometers (NexGen Ergonomics) with 100Hz low-pass pre-amp filters were used (Page et al., 2017). One accelerometer was mounted on the subject's head, with the use of a rigid plastic ratchet head band that was adjustable to the point of being tightly held against the middle of the forehead. A second accelerometer was mounted at the subject's low back location (approximately at the L4/L5 level) with the use of a rigid belt. Both accelerometers were connected to a portable, wearable Biometrics data logger and the collected acceleration data was stored on a 2GB flash card. The activities performed were also video recorded. The video record was synchronized with the accelerometer traces to support identification of peak accelerations.

Biometrics software was used to process the acceleration data in each of the three axes (x, y, z) and exported as comma-separated .TXT files with the data shown in the engineering units of meters per second per second (m/sec^2). Excel was used to calculate the vector sum for each sampled (500Hz) moment in time. Peak accelerations were identified for each axis, in each direction (+/-) and for the vector sum.

Two subjects performed select activities. "Hop down 2 steps" and "hard braking from 15mph" were smoothed at increasing levels of averaging and plotted, using simple moving averages with window sizes of 3, 6, and 10 data points. The first smoothed data point is calculated by taking an average of the 1^{st} through n^{th} data points, as described in Equation 1. The

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second smoothed data point is calculated by taking an average of the 2nd through n+1 data points, and so on. A 10-sample window represents 1/50th of a second

$$\text{Smoothed Data Point \#1} = \frac{(d^1 + d^2 + \ldots + d^n)}{n} \quad \text{Where } n = 3, 6, \text{ or } 10. \qquad (1)$$

3. Results

The practical approach of measuring peak acceleration is to sample over a period of time, and within that period, identify a peak acceleration. Sometimes for human activities like walking or running, a peak acceleration for each stride may be identified and then all strides averaged. In this study, the window of consideration of the raw data ranged from 3s-24s, depending upon the human activity, and the peak acceleration was taken from a single sample point. Tables 1 and 2 present the peak accelerations in each coordinate axis and the vector sum, for both the head and low back. Since the values in g's in Tables 1 & 2 are taken from the maximum value during the sampling period of each specific activity, they may or may not occur on the same 1/500Hz sample (in fact, most do not). As expected, across activities, the peak vector sum exceeded the maximum individual axis peak accelerations in all activities ranging from 0.06%-22.09% for the head and 0.50%-32.89% for the low back.

Table 1: Subject 1 Peak Acceleration Results.

Activity	Head Located Accelerometer (g)							Low back Located Accelerometer (g)						
	+z	-z	+y	-y	+x	-x	xyz	+z	-z	+y	-y	+x	-x	xyz
Casual Walking	1.03	0.41	0.47	0.41	0.49	0.64	1.09	1.13	0.48	0.89	0.77	0.70	1.08	1.38
Fast Walking	1.98	0.69	0.86	0.78	0.69	0.44	2.01	1.63	0.86	1.12	1.39	0.76	1.09	1.84
Slow Jogging	2.71	1.26	0.74	0.83	0.75	0.50	2.80	3.16	2.01	3.98	2.34	0.99	3.59	4.73
Fast Jogging	4.29	1.86	1.04	1.25	1.08	0.62	4.30	5.26	2.69	4.71	4.14	1.26	4.95	7.84
Jumping	4.58	1.69	0.67	0.92	1.67	1.88	4.58	6.97	2.88	2.30	2.46	2.76	4.34	7.40
Walk up stairs	1.16	0.51	0.45	0.52	0.42	0.71	1.25	1.29	0.61	0.62	0.65	0.43	0.98	1.39
Walk down stairs	1.62	0.59	0.42	0.52	0.37	0.90	1.63	2.08	0.74	1.82	1.71	0.73	1.73	2.93
Ascend stairs quickly	1.09	1.41	0.93	0.84	0.67	1.23	1.51	1.84	1.95	1.00	0.94	0.63	1.04	2.00
Descend stairs quickly	2.23	1.99	0.77	1.07	0.51	1.33	2.24	3.98	1.86	2.56	3.37	2.60	2.65	4.30
Hop down 1 step	4.66	1.20	0.75	0.41	1.52	1.17	4.72	10.00	1.50	4.96	3.57	2.38	7.47	10.96
Hop down 2 steps	5.31	3.01	0.78	0.87	2.52	1.06	5.58	8.91	1.71	6.56	3.24	2.44	6.04	10.97
Hard braking from 5 MPH	0.59	0.19	0.22	0.22	0.90	1.03	1.04	0.15	0.09	0.00	0.16	0.47	0.82	0.83
Hard braking from 10 MPH	0.53	0.48	0.36	0.25	1.05	1.68	1.72	0.42	0.13	0.14	0.18	0.53	1.00	1.05
Hard braking from 15 MPH	0.83	2.37	0.98	0.76	2.67	2.22	3.43	0.84	0.41	0.22	0.27	0.56	0.97	1.06
Plop in chair	2.12	1.26	0.33	0.46	1.43	1.49	2.25	4.03	1.20	1.20	1.37	2.52	0.58	4.08

Table 2: Subject 2 Peak Acceleration Results.

Activity	Head Located Accelerometer (g)							Low back Located Accelerometer (g)						
	+z	-z	+y	-y	+x	-x	xyz	+z	-z	+y	-y	+x	-x	xyz
Casual Walking	0.87	0.42	0.34	0.25	0.43	0.50	0.97	0.89	0.45	0.97	0.72	0.48	0.66	1.39
Fast Walking	1.45	0.76	0.45	0.38	0.64	0.50	1.51	1.04	0.98	1.24	1.25	0.86	1.22	1.72
Slow Jogging	1.76	1.14	0.39	0.30	0.83	0.62	1.93	2.03	1.78	2.20	2.13	0.62	1.92	2.93
Fast Jogging	2.23	1.27	0.37	0.44	0.80	0.48	2.23	3.56	2.22	3.72	2.48	0.67	3.50	5.18
Jumping	5.06	2.92	0.81	0.57	1.92	1.02	5.14	8.82	3.58	1.22	1.14	2.43	6.42	8.90
Walk up stairs	0.78	0.45	0.37	0.38	0.51	0.51	0.87	0.98	0.46	0.91	0.68	0.46	0.78	1.17
Walk down stairs	1.00	0.74	0.41	0.36	0.68	0.37	1.02	1.29	0.77	0.78	0.99	0.46	0.98	1.52
Ascend stairs quickly	1.27	1.15	0.31	0.50	0.95	0.70	1.55	3.54	1.79	1.39	1.62	0.86	0.80	3.64
Descend stairs quickly	2.79	1.29	0.36	0.36	0.76	0.49	2.79	3.67	1.85	1.69	1.25	0.82	1.82	3.78
Hop down 1 step	4.70	1.08	0.54	0.38	1.26	0.62	4.70	8.06	1.34	3.66	4.42	1.47	3.15	8.61
Hop down 2 steps	5.88	1.89	0.44	0.33	2.45	0.87	6.10	9.96	1.72	3.61	3.55	1.59	4.93	10.69
Hard braking from 5 MPH	0.66	0.46	0.23	0.44	0.32	1.97	1.97	0.22	0.12	0.06	0.08	0.40	0.90	0.91
Hard braking from 10 MPH	0.68	1.21	0.42	0.40	1.01	2.04	2.08	0.48	0.10	0.12	0.16	0.44	1.12	1.14
Hard braking from 15 MPH	0.67	0.41	0.44	0.31	0.73	1.99	2.07	0.58	0.38	0.18	0.44	0.60	1.26	1.28
Plop in chair	2.50	0.98	0.35	0.38	1.28	0.79	2.75	4.03	1.72	0.67	0.62	2.35	0.63	4.05

In Tables 3 and 4, the individual axis peak acceleration instances are reported relative to the vector sum instance. The vector sum peak acceleration, for each activity, was set at time zero, within the full window of consideration of the raw data.

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The values in Tables 3 & 4 are simply the difference in time (s) that the individual axis peak accelerations occurred relative to the time that the vector sum peak acceleration occurred to the 1/500th of a second.

Table 3: Subject 1 Duration Between Individual Axis Peak and Vector Sum Peak.

Activity	Head Located Accelerometer (s)							Low back Located Accelerometer (s)						
	+z	-z	+y	-y	+x	-x	xyz	+z	-z	+y	-y	+x	-x	xyz
Casual Walking	0.002	-2.370	5.566	7.310	-1.616	-6.232	0.000	2.664	0.734	-1.014	-0.518	2.010	4.236	0.000
Fast Walking	0.002	-0.612	-0.386	-1.676	0.926	-0.362	0.000	-0.002	8.678	11.784	12.276	3.984	2.188	0.000
Slow Jogging	0.000	3.156	-0.002	1.164	2.188	-1.834	0.000	0.000	-1.112	1.456	0.040	6.552	1.448	0.000
Fast Jogging	0.000	-0.714	-0.908	0.048	5.756	-2.272	0.000	0.334	-1.756	0.004	0.036	-1.552	0.000	0.000
Jumping	0.000	0.010	12.176	12.550	-0.006	0.074	0.000	0.000	9.032	-3.122	-3.104	-3.098	-3.126	0.000
Walk up stairs	0.000	2.764	1.218	0.612	-4.888	-0.472	0.000	1.152	2.720	-2.442	1.132	2.304	-0.008	0.000
Walk down stairs	0.000	-1.674	-0.380	0.088	3.728	-1.906	0.000	0.004	-1.698	-0.486	-0.006	-2.456	-0.002	0.000
Ascend stairs quickly	0.714	1.142	-0.002	1.044	0.846	0.008	0.000	0.072	0.000	0.576	1.418	0.008	1.398	0.000
Descend stairs quickly	0.000	0.610	1.208	0.966	0.592	0.392	0.000	0.000	-0.052	0.556	0.306	-0.586	0.546	0.000
Hop down 1 step	0.000	-8.978	0.034	-8.738	-0.004	-8.684	0.000	0.000	8.686	8.756	0.012	0.022	-0.008	0.000
Hop down 2 steps	-12.486	-12.474	0.106	-6.060	-12.492	-12.418	0.000	0.000	6.352	0.002	12.498	0.032	-0.006	0.000
Hard braking from 5 MPH	0.304	0.028	1.278	-0.102	0.360	0.000	0.000	-0.232	0.394	0.156	-0.016	0.168	0.000	0.000
Hard braking from 10 MPH	0.458	0.588	0.508	-0.078	0.604	0.000	0.000	-0.002	-0.064	0.208	-0.164	0.228	-0.258	0.000
Hard braking from 15 MPH	-0.052	0.000	-0.002	0.060	0.014	-0.872	0.000	-0.202	-0.156	-0.106	0.016	0.438	-0.336	0.000
Plop in chair	0.000	-4.852	-4.828	2.014	0.326	-5.160	0.000	0.000	-5.432	-5.180	-5.204	-5.812	-12.826	0.000

Table 4: Subject 2 Duration Between Individual Axis Peak and Vector Sum Peak.

Activity	Head Located Accelerometer (s)							Low back Located Accelerometer (s)						
	+z	-z	+y	-y	+x	-x	xyz	+z	-z	+y	-y	+x	-x	xyz
Casual Walking	0.000	-0.214	0.092	0.676	-0.004	1.160	0.000	-1.110	-3.680	-0.002	-0.552	-0.076	-1.136	0.000
Fast Walking	0.000	-0.726	0.566	3.074	0.480	3.050	0.000	0.950	0.268	-0.466	-0.950	-0.518	-0.010	0.000
Slow Jogging	0.000	1.478	-0.418	2.468	-0.004	-2.202	0.000	0.000	0.694	-0.002	0.414	0.006	2.426	0.000
Fast Jogging	0.000	-1.848	-2.292	-1.030	-0.632	-2.194	0.000	0.002	-0.114	-0.002	0.380	-1.148	-0.016	0.000
Jumping	0.000	2.674	2.536	2.736	0.038	2.674	0.000	0.000	2.706	-0.010	0.002	0.014	-0.012	0.000
Walk up stairs	-2.608	-0.280	0.126	0.748	-0.028	1.156	0.000	1.070	3.254	0.002	0.550	-0.098	1.050	0.000
Walk down stairs	0.000	-0.208	-2.342	-3.034	1.030	-0.776	0.000	0.002	-0.210	-0.484	-0.894	-0.200	-0.504	0.000
Ascend stairs quickly	-0.022	-0.218	-0.078	-0.356	-0.004	0.900	0.000	0.000	-0.062	0.654	0.616	-0.078	-0.346	0.000
Descend stairs quickly	0.000	0.016	0.080	-0.850	-0.010	-0.442	0.000	0.000	-0.050	-0.550	-1.074	0.000	-0.028	0.000
Hop down 1 step	0.000	0.016	0.008	1.196	-0.012	1.694	0.000	0.004	3.544	0.016	-0.004	0.020	-0.012	0.000
Hop down 2 steps	0.000	0.028	0.066	0.014	-4.008	-2.426	0.000	-4.004	0.032	0.004	0.018	0.028	-0.004	0.000
Hard braking from 5 MPH	0.322	0.494	-0.512	0.162	0.520	-0.004	0.000	-0.260	0.382	-0.698	0.118	0.172	0.000	0.000
Hard braking from 10 MPH	0.058	0.730	0.726	0.188	0.730	0.000	0.000	0.052	-3.036	0.068	-0.118	0.430	0.000	0.000
Hard braking from 15 MPH	0.052	1.034	-0.016	0.188	0.888	-0.002	0.000	-0.032	0.022	0.004	-0.030	0.602	0.000	0.000
Plop in chair	0.000	-3.848	-4.192	0.286	-4.266	-4.396	0.000	0.000	0.076	-4.186	0.076	0.014	-1.422	0.000

Table 5: Subject 1 Components of Peak Vector Sum Acceleration.

Activity	Head Located Accelerometer (g)				Low back Located Accelerometer (g)			
	z	y	x	xyz	z	y	x	xyz
Casual Walking	1.03	0.13	-0.32	1.09	0.76	-0.85	-0.78	1.38
Fast Walking	1.97	-0.03	-0.39	2.01	1.63	0.76	-0.41	1.84
Slow Jogging	2.71	0.68	0.15	2.80	3.16	-3.39	-0.96	4.73
Fast Jogging	4.29	0.10	-0.20	4.30	4.45	-4.14	-4.95	7.84
Jumping	4.58	0.10	-0.14	4.58	6.97	-0.84	2.34	7.40
Walk up stairs	1.16	0.11	0.47	1.25	1.13	-0.47	-0.65	1.39
Walk down stairs	1.62	0.01	0.13	1.63	1.92	1.38	-1.72	2.93
Ascend stairs quickly	0.07	0.92	1.20	1.51	-1.95	-0.10	0.44	2.00
Descend stairs quickly	2.23	0.21	-0.05	2.24	3.98	-1.62	0.21	4.30
Hop down 1 step	4.66	-0.03	-0.74	4.72	10.00	-4.41	-0.84	10.96
Hop down 2 steps	5.30	0.72	-1.58	5.58	8.91	-6.33	-0.92	10.97
Hard braking from 5 MPH	-0.10	-0.12	1.03	1.04	0.09	0.08	-0.82	0.83
Hard braking from 10 MPH	-0.36	0.10	1.68	1.72	0.36	0.09	-0.98	1.05
Hard braking from 15 MPH	-2.37	0.79	-2.35	3.43	0.67	0.01	-0.81	1.06
Plop in chair	2.12	0.06	-0.74	2.25	4.03	0.30	0.61	4.08

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Table 6: Subject 2 Components of Peak Vector Sum Acceleration.

Activity	Head Located Accelerometer (g)				Low back Located Accelerometer (g)			
	z	y	x	xyz	z	y	x	xyz
Casual Walking	0.87	0.02	-0.43	0.97	0.80	-0.96	-0.62	1.39
Fast Walking	1.45	-0.06	-0.42	1.51	0.84	1.05	-1.08	1.72
Slow Jogging	1.76	-0.02	-0.79	1.93	2.03	-2.12	0.16	2.93
Fast Jogging	2.23	0.07	0.04	2.23	3.53	-3.72	-0.75	5.18
Jumping	5.06	0.25	-0.84	5.14	8.82	0.87	-0.79	8.90
Walk up stairs	0.74	0.11	-0.46	0.87	0.41	-0.90	-0.62	1.17
Walk down stairs	1.00	-0.06	-0.16	1.02	1.28	0.81	0.11	1.52
Ascend stairs quickly	1.22	0.16	-0.94	1.55	3.54	0.82	0.31	3.64
Descend stairs quickly	2.79	-0.06	0.08	2.79	3.67	-0.43	0.82	3.78
Hop down 1 step	4.70	0.16	-0.04	4.70	7.87	3.40	0.80	8.61
Hop down 2 steps	5.88	0.29	-1.57	6.10	9.96	-2.98	-2.48	10.69
Hard braking from 5 MPH	0.13	-0.06	1.97	1.97	0.12	0.03	-0.90	0.91
Hard braking from 10 MPH	0.35	0.20	2.04	2.08	0.23	-0.01	-1.12	1.14
Hard braking from 15 MPH	0.44	0.37	1.99	2.07	0.22	-0.11	-1.26	1.28
Plop in chair	2.50	-0.07	-1.16	2.75	4.03	0.40	-0.05	4.05

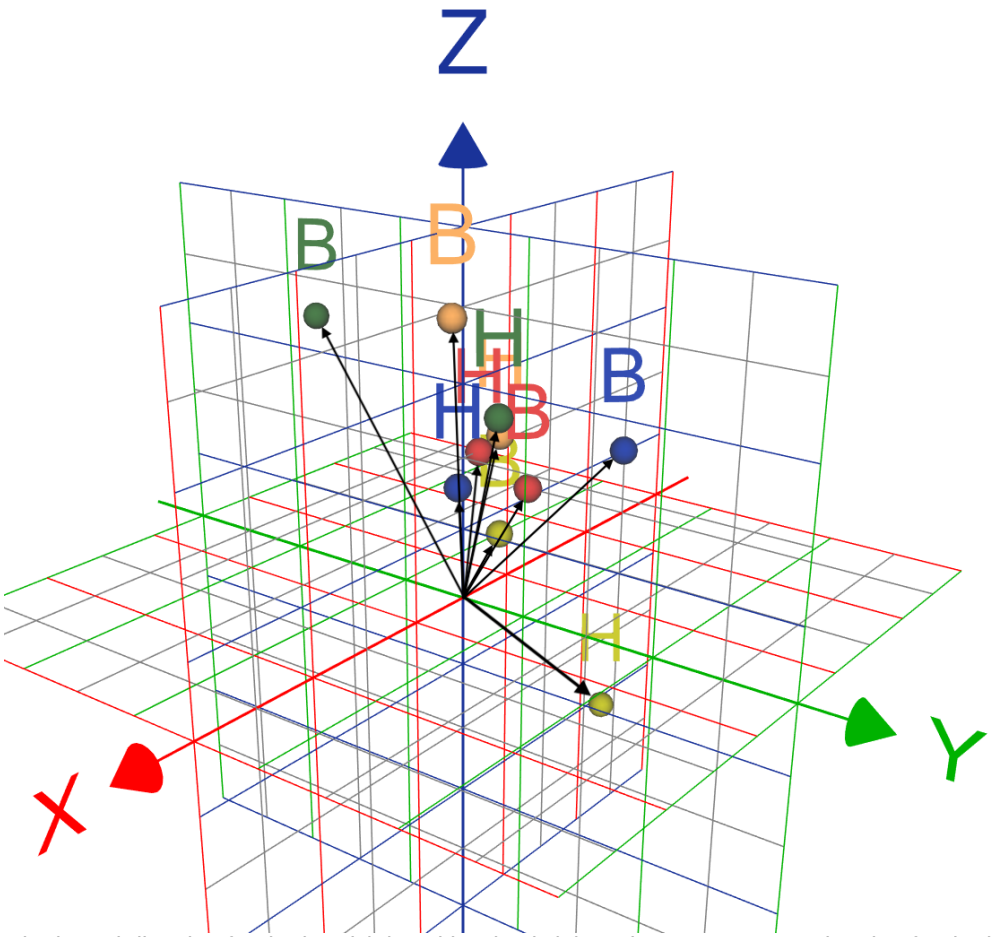

Figure 1: Magnitude and direction for the head (H) and low back (B) peak vector sum acceleration for the human activities of “fast walk” (red), “slow jogging” (green), “walk down stairs” (blue), “plop in chair” (orange) and “hard braking from 15mph” (yellow).

Tables 5 and 6 are the vector sum peak accelerations, and their respective x, y, z component accelerations for subjects 1 and 2 respectively, for each human activity. Figure 1 shows the magnitude and direction for the head (H) and low back (B) peak vector sum acceleration for the human activities of “fast walk” (red), “slow jogging” (green), “walk down stairs” (blue), “plop in chair” (orange) and “hard braking from 15mph” (yellow). Figure 2 shows the results of data smoothing for “hard braking

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from 15mph" and "hopping down two steps". The left side plots in Figure 2 are of a zoomed-out window of the data, while the right-side plots are of a zoomed-in window. Each plot shows no smoothing (blue), Window=3 (red), Window=6 (grey) and Window=10 (yellow) level of smoothing. These exemplar plots of peak vector sum acceleration present that as acceleration is more slowly changing over time, smoothing does not materially affect the change or magnitude of the acceleration plot. However, as the plot of the acceleration changes more rapidly over time, increasing levels of smoothing both dampens this rapid change and reduces the magnitude of the peak.

Figure 2: Plots of "hard braking from 15mph" and "hopping down two steps". The left side plots are of a zoomed-out window of the data, while the right side plots are of a zoomed-in window. Each plot shows no smoothing (blue), Window=3 (red), Window=6 (grey) and Window=10 (yellow) level of smoothing.

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4. Discussion

Accelerometer instrumentation used to measure human activity is very useful for directly measuring accelerations experienced by the human body. Accelerometer and data logging instrumentation are portable and wearable and allow this type of data to be captured without interruption of human movement. Peak acceleration provides information that can be helpful in various scientific disciplines, including ergonomics and health and safety. This paper shows some considerations in the analysis and interpretation of peak acceleration results.

Depending on the objective, it may be adequate to consider the peak acceleration in any one axis, or it may be more appropriate to analyze the vector sum. Over the compendium of human activities evaluated in this study, the vector sum has been shown to exceed the magnitude of the individual axis peaks by averages of 4.53% for the head and 11.38% for the low back. The largest magnitudes were associated with human activities that result in off-axis vector sum peak acceleration such as walking, jogging ascending stairs, braking in a car and plopping in a chair. The actual sample of the occurrence of the peak acceleration was almost always different when comparing any individual axis peak to the vector sum peak, surprisingly. This result was somewhat unexpected and further supports the need to consider a 3-dimensional peak acceleration analysis, should the human activity not relate to a uni-directional movement.

There was a notable difference between the magnitude and direction of the peak vector sum acceleration when comparing the head with the low back, as illustrated in Figure 1. In most human activities measured, the low back acceleration magnitude exceeded the head acceleration magnitude, likely because the spine offered a buffering to any external forces on the body that created the acceleration. Hard braking activities were the reverse for head and low back acceleration which was somewhat expected due to the freedom of movement of the head compared with the seatbelt control of the low back.

Close examination of the acceleration plots, particularly at the point of the peak acceleration, in some cases demonstrated multiple peaks within hundredths of a second. These acceleration results may be considered for their representation of actual human movement. With the assumption that this type of data result is not instrument related, then it may be reasonable to consider that there is movement of the accelerometer that is independent from the movement of the body. Smoothing techniques were used to show the impact of treating data that may contain independent accelerometer movement. Smoothing the data is effective for reducing the impact of independent accelerometer movement at the moment of a peak acceleration but at the cost of reducing the magnitude of the peak to the point where it may no longer be the peak acceleration, particularly in human activities involving repeated peak accelerations.

5. Conclusions

Measuring peak accelerations of human activity involves several considerations. A general appreciation of the kinematics of the human activity can help consider a single axis or multi-axis analysis. Generally, the head and low back peak acceleration has been studied, but consider that they have been shown here to have notably different results in 3-dimensional analysis for their magnitude and direction. The actual moment in time of the peak acceleration changes, in consideration of whether an individual axis peak or the vector sum peak is analyzed. The data, at the point of the peak acceleration, needs to be examined for its representativeness for the human activity measured, and for the application of smoothing and its impact considered. While this paper may add to the overall information on peak acceleration of human activity, it more importantly serves to provide additional research with some basic considerations for its measurement and analysis.

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