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Accelerations of the Locomotive Cab Space and Locomotive Engineer During Coupling Events and Their Comparison to Typical Human Activity -A Case Study

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Abstract: The accelerations that humans experience has been investigated for several years, in various different work and life environments. This case study provides the results of the accelerations in the locomotive cab space and of the head of the cab space occupant during coupling events. The cab space occupant was seated in the locomotive engineer's position without any restraints. Coupling events were conducted at 1-4 mph speeds while accelerations were measured at the occupant seat pan, locomotive floor and the head of the occupant. 10G accelerometers were used to quantify the peak accelerations at each location. The train consist was made up of 3 1500hp switching locomotives with 2 gondola cars, that were then coupled to a stationary set of 10 gondola cars with the required handbrakes applied. The subject was seated in the locomotive seat at an approximate 45º angle to the direction of movement. The locomotive seat had a round, cushioned seat pad and a backrest but with no arm rests. The subject sat with hands on the control levers and was un-restrained. The train movement was remote controlled and the subject was given no indication of when the actual coupling took place. Accelerations were also measured at the head and low back simultaneously, during typical human activities. Acceleration magnitudes were highest from the locomotive floor and reduced at the locomotive seat pan and further still at the head. Couplings at the higher speeds of 3 and 4 mph were subjectively noticeable, however they did not elicit accelerations at the seat pan or head that were any greater than several typical human activities. Locomotive crews work together to switch railroad cars with attention towards experiencing the least amount of in-cab accelerations as possible. This paper serves to support that maximum allowed coupling speeds result in less exposure to accelerations of the body than typical human activity.

Keywords: Locomotive, Acceleration, Safety

1. Introduction

Switching rail cars with the use of locomotives has been a common activity in the railroad industry since the industry's inception. This activity, when performed with an on-board locomotive engineer, involves that crew members on the ground provide radio communications (or hand signals) to guide the engineer to control the train movement during the coupling event. It has been such that coupling events be restricted to 4mph or less throughout the railroad industry. Coupling events at the upper range of the 4mph practice have been subjectively characterized by locomotive engineers as a "hard hit", for example. In some instances, there have been reports of musculoskeletal symptom onset reported by occupants of locomotives, from an experience of a "hard hit", though these reports are very uncommon. A train or cut of cars are connected to each other by a coupler mechanism and drawbar, which is connected to the locomotive's or rail freight car's draft gear. The draft gear acts as a shock absorber by allowing the drawbar to slide in the fore-aft direction, effectively compressing or rebounding depending on the forces acting upon it. "Buff" forces cause the drawbar to be compressed while "Draft" forces cause the drawbar to be extended. During coupling events, the series of draft gears in a train can isolate the locomotive cab space from any accelerations due to a coupling event. If the series of draft gears are compressed to any degree (this could happen due to train movement, track grade, and train handling), there may be a decrease in any isolation of the cab space from a coupling event acceleration. Also, the number of draft gears between the cab space and the point of the coupling may serve to provide greater isolation of the cab from coupling event accelerations (i.e., greater numbers improve isolation).

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This case study measured the same subject during exposures to both on-board locomotive coupling events, and several human activities for peak accelerations of the body (head and low back). The measurements serve to provide an understanding of safety of the cab space occupant during coupling events.

2. Methods

Three switching locomotives (SW1000's) as shown in Figure 1, coupled to two gondola cars were used to couple onto 10 stationary gondola cars. The coupling events were conducted on an uphill grade, which would effectively compress the series of drawbars in the train. The 10 stationary gondola cars had their hand brakes applied in accordance with railroad rules requirements. The locomotive consists and the two coupled cars were remote controlled by a qualified operator. The subject (52-year-old male, 5'7", 175lbs) sat in the locomotive engineer's seat. The locomotive engineer's seat was a round cushion seat with a backrest and no armrests as shown in Figure 2. The seat was oriented at an approximate 45º angle to the AAR control stand. The subject sat looking forward, with their hands on the throttle and braking levers, which is a typical locomotive engineer operating position. Without any radio contact during coupling events, nor having any control of the train movement, the actual moment of the coupling event was unknown to the subject. Three trials of coupling were performed at 1, 2, 3 and 4mph. Speed was able to be monitored through the remote-control operator's control box. For purposes of comparison, the subject participated in various typical human activities, while collecting head and lumbar spine accelerations.

The coupling events were video recorded at 3 different field of views. One field of view was of the seated subject, the second was out the front of the lead locomotive, and the third was an external view of the railroad cars at the point of the coupling event. At the start and end of data collection, each of the video cameras and accelerometers were synchronized in time, and thus the video record could be used to characterize each coupling event and match them up with the measured accelerations.

To record accelerations for coupling events, three 10G 3-axis accelerometers (NexGen Ergonomics) were used (Page et al., 2017). One accelerometer was mounted to the floor of the cab space under the engineer's seat. Another accelerometer was fixed to the seat pad of the engineer's seat, having been mounted in a rubberized disc, and positioned under the ischial tuberosities. The third accelerometer was mounted on the subject's head, with the use of a plastic ratchet head band, taken from a hard hat. This device allowed for the accelerometer to be firmly fixed to the head band by the supplied accelerometer bolt and thus head acceleration measurement accuracy is optimized. The location of the accelerometer on the head was the middle forehead. Throughout the coupling events, measured accelerations were captured onto a 2GB flash cards by two identical Biometrics data loggers. For human activity data collection, the head-mounted accelerometer was used in identical fashion as for coupling event data collection. A lumbar located accelerometer was used in place of a seat-mounted accelerometer. The lumbar located accelerometer was mounted with the use of a waist belt and firmly fixed by the supplied accelerometer bolt.

The three recorded accelerometer traces for the three axis (x, y, & z) were plotted using Biometrics software. The combined video and accelerometer synchronized records permitted identification of each coupling trial in the accelerometer traces. As there are accelerations in all 3-axis, a vector sum was calculated for each sampled (500Hz) moment in time, and the peak vector sum was determined. This same general process was applied to the various human activity trials to also arrive at the peak vector sum acceleration for each activity.

Figure 1: Switching Locomotive Consist consistent with the one used to conduct the case study and the subject seated in the engineer's position.

3. Results

Figure 2: Sequence of frame grabs of a video record of a 4mph coupling event presented left to right, row by row. The sequence of events is a single movement of the head/torso unit forward, followed by a return to the original seated position.

The video record of the subject during coupling events shows that there was a visually repeatable body movement, that characteristically increased in magnitude, as the coupling speed increased. Figure 2 is an example of the sequence of movements that the subject experienced during a 4mph coupling event. There was no appreciable cervical spine motion. The head and shoulders moved forward approximately 18" upon coupling and subsequently returned to their pre-coupling position without any notable whiplash-type movement of any kind. For a 1mph trial, the head and shoulders moved forward approximately 8". The subject remained seated during all coupling event trials and was not knocked out of the locomotive engineer's seat. The subject did not experience any symptoms of any kind, during or after the coupling events.

While the characteristics of the subject's body movements were visually repeatable across coupling event trials, the moment that the peak acceleration of the head occurred did vary among the trails. Table 1 provides a description of at what point the peak acceleration occurred, and what the characteristic body movement was, at that moment.

Table 1: Description of the body movement during coupling events at the time of the peak acceleration.

Trial	Target Speed (mph)	Description of Body Movement at Moment of Peak Acceleration
1	1	Forward movement of the head and shoulders stops
2	1	Forward movement of the head and shoulders stops
3	1	Forward movement of the head and shoulders stops
4	2	Forward movement of the head and shoulders stops
5	2	Forward movement of the head and shoulders stops
6	2	Mid-point of forward movement of the head and shoulders
7	3	Head returns to starting position
8	3	Forward movement of the head and shoulders stops
9	3	Mid-point of forward movement of the head and shoulders
10	4	Forward movement of the head and shoulders stops, head rotated (y is fore-aft)
11	4	Mid-point of forward movement of the head and shoulders
12	4	Forward movement of the head and shoulders stops

Table 2 provides the detailed results of the peak accelerations of the coupling event trials, based on a determination of the vector sum at each sampling point (500Hz). The remote operator was making every effort to achieve the target speed. The remote operator's control box contained a readout for miles per hour (mph) that was accurate to one tenth of a mph and measured via a GPS system. Based on the data capture of the control box, all trials were within ±0.1mph of the target speed. The direction of acceleration in Table 2 is fore/aft = positive/negative X, right/left = positive/negative Y, and up/down = positive/negative Z. All three accelerometers were aligned with their X-axis to match the principal direction of fore/aft movement of the train. While the movement of the head of the subject was not restricted, the subject was looking forwards during coupling events and as such, the head accelerometer was aligned with the other two accelerometers.

Table 2: Peak accelerations of the coupling events.

Trial		Peak Head Acceleration					Peak Seat Pan Acceleration					Peak Cab Floor Acceleration				
Target Speed (mph)	Elapsed Video Time	Max Vector Sum (g)	Corresponding X (g)	Corresponding Y (g)	Corresponding Z (g)	Time of Occurrence	Max Vector Sum (g)	Corresponding X (g)	Corresponding Y (g)	Corresponding Z (g)	Time of Occurrence	Max Vector Sum (g)	Corresponding X (g)	Corresponding Y (g)	Corresponding Z (g)	Time of Occurrence
1	0:14:47	0.34	-0.32	-0.04	0.07	0:14:48	0.43	-0.41	-0.09	0.10	0:14:47	0.44	-0.43	-0.05	0.08	0:14:47
1	0:16:42	0.39	-0.24	-0.19	0.23	0:16:43	0.35	0.29	-0.18	-0.03	0:16:43	0.44	-0.41	0.05	-0.17	0:16:43
1	0:18:13	0.44	-0.36	-0.12	0.23	0:18:14	0.57	-0.56	-0.10	0.10	0:18:13	0.58	-0.57	0.01	-0.09	0:18:13
2	0:21:19	0.54	-0.53	-0.07	-0.01	0:21:20	0.74	-0.71	-0.11	0.20	0:21:19	0.75	-0.75	0.03	0.05	0:21:19
2	0:22:31	0.53	-0.43	0.14	0.14	0:22:32	0.59	-0.56	-0.14	0.12	0:22:31	0.57	-0.57	0.00	0.01	0:22:31
2	0:23:44	0.70	-0.26	-0.18	-0.62	0:23:44	0.97	-0.96	0.06	0.15	0:23:44	0.97	-0.97	-0.01	-0.04	0:23:44
3	0:25:00	0.60	0.48	0.03	-0.36	0:25:01	0.92	-0.89	-0.14	0.16	0:25:00	0.95	-0.93	0.02	-0.17	0:25:00
3	0:25:48	1.18	-1.15	-0.15	0.22	0:25:48	1.91	-1.90	0.21	-0.06	0:25:48	2.00	-1.96	0.02	0.37	0:25:48
3	0:27:02	0.61	-0.30	-0.15	-0.52	0:27:03	1.01	-0.98	-0.05	0.24	0:27:03	1.09	-1.08	-0.03	0.13	0:27:03
4	0:28:11	1.52	-0.50	-1.30	-0.61	0:28:11	2.78	-1.84	1.85	0.94	0:28:11	2.44	-2.43	0.10	0.19	0:28:11
4	0:32:24	0.74	0.10	-0.38	-0.63	0:32:25	0.91	-0.89	0.03	0.17	0:32:25	1.09	-1.07	-0.07	0.19	0:32:25
4	0:34:05	1.06	-0.94	-0.14	-0.46	0:34:06	2.38	-2.34	-0.07	0.40	0:34:06	2.22	-2.22	0.02	0.13	0:34:06

To demonstrate the relative magnitudes of the peak accelerations during coupling events, several different human activities were performed by the same subject. None of the human activities would be considered to cause tissue damage to the human body. Figure 2 shows the peak accelerations in g's.

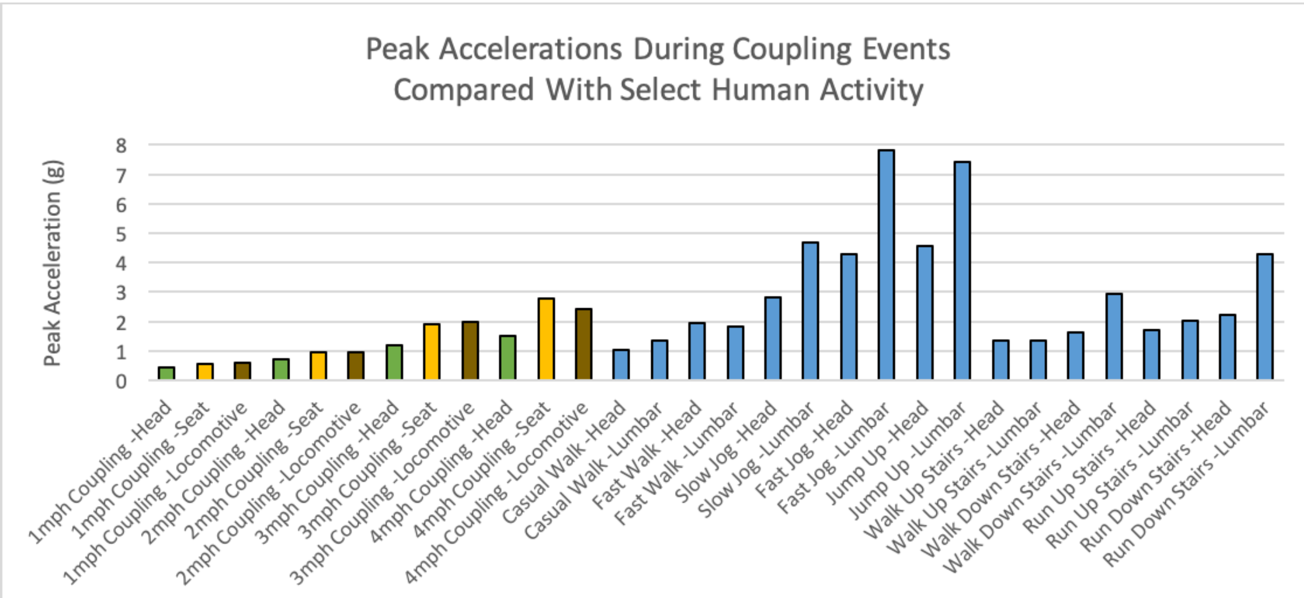

Figure 2: Peak Accelerations of Coupling Events and Human Activity.

4. Discussion

Railroad employees who are on locomotives are trained to protect themselves against unexpected movement. The subject of this case study was aware of pending coupling events, but was not aware of the specific moment that they took place. It is normal practice for the engineer to be seated while coupling his train with other cars. The locomotive engineer would receive a countdown to the point of the coupling event, from his crewmember located on the ground at the coupling point. This case study provided an evaluation of the body movements of an individual in the locomotive engineer's seat, during anticipated coupling events but without communication with any ground crewmember.

This case study of accelerations experienced on board locomotives during coupling events helps to provide meaningful data for health and safety practitioners, as well as railroad operations, as to the risk to the occupants of the cab space. Others have measured accelerations of the cab space occupant during coupling events. Serina et al. (2009) recorded head accelerations during coupling events of 1-5mph with the use of a single locomotive. This testing resulted in peak head accelerations of 0.75g for couplings where the subject was facing the direction of movement and 0.93g for when the subject was facing backwards to the direction of movement. Generally, the peak acceleration of the locomotive during coupling events measured by Serina et al. (2009) were approximately half the magnitude of the peak accelerations presented in Table 2, in this paper. Larson et al. (2001) measured coupling events with accelerometers and reported that under regularly assigned switching operations, peak accelerations experienced in the cab space were characteristically mild. Larson et. al. (2001) also staged coupling events that did not exceed a velocity change of 1mph with associated peak accelerations less than 2g. A number of "activities of daily living" were reported by Grieser et al. (2013), Larson et al. (2001) and Allen et al. (1994), which are consistent with the human activity peak accelerations reported in this case study. As were the findings in this case study, others measuring peak accelerations during occupational and daily living environments did not receive any reports from subjects of any symptoms about their body, as a result of these exposures (Allen et al., 1994, Larson et al., 2001, Serina et al., 2009, Grieser et al., 2013, Page et al., 2017).

The use of the same subject in this case study for both measurements during coupling events and human activity provide a degree of control in the interpretation of the results by limiting the issue of subject variability, but it also limits the findings' application to the population. Other similar research did not report that the same subject was used for both coupling events and human activity conditions (Larson et al., 2001). While human activity peak accelerations have been reasonably consistent across the various research papers discussed above, it seems to have been less consistent for coupling events. As mentioned, train makeup, train size, train handling, coupling speed, track grade, and the specific amount of draft gear buff and slack are some of the variables that can affect peak acceleration in the locomotive cab space. In the real-life railroad environment, the many variables that can have an effect on peak acceleration during a coupling event are not easily repeatable to a high level of precision, for purposes of executing a controlled experiment. What was consistent, however, was that the peak acceleration magnitudes during coupling events were at the low-end of peak accelerations measured during several common human activities.

5. Conclusions

Peak accelerations of the locomotive cab occupant during coupling events in this case study were at the low end compared with numerous measurements of human activity, for both seat mounted (i.e., lumbar spine) and head mounted locomotive cab occupant accelerometer measurements. This case study's (i.e., 1 subject) results suggest that there is not an increased risk of injury to the seated locomotive cab occupant during coupling events and serves to affirm the safety of the environment in the locomotive cab space during coupling events at acceptable train speeds of 4mph or less.

6. References

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