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EFFECTS OF ENVIRONMENTAL FACTORS ON NATURALISTIC DRIVING IN OBSTRUCTIVE SLEEP APNEA

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Summary: Reduced visibility and other environmental factors can impair driver ability to respond to roadway hazards. We examined the effects of reduced visibility on naturalistic driving in 66 drivers, including 45 at-risk drivers with obstructive sleep apnea (OSA) and 21 controls. We analyzed three months of electronic data using "black box" recorder technology and assessed the extent to which driver speed, longitudinal acceleration, and lateral acceleration metrics depend on ambient visibility from web-based environmental data archives. We calculated summary driving metrics within 10-second intervals, and reduced these to within-subject means and tested for associations of interest. OSA drivers did not differ from controls with respect to electronic measures or visibility conditions in which they drove. On average, drivers drove slower when visibility was reduced. After controlling for speed, variations in lateral and longitudinal acceleration were positively associated with high-visibility conditions. These findings suggest that drivers exert greater vehicular control when visibility is limited, and that this association is not just due to slower speeds. Weaker relationships between visibility and driving measures in OSA suggest reduced adaptive strategies. Our methods provide a framework for analyzing the effects of other environmental factors on driving, and we provide an additional example using wind speed.

INTRODUCTION

Driving performance and safety depend critically on environmental factors, such as visibility, precipitation, and wind speed. For example, poor visibility may impair driver hazard avoidance leading to more sudden swerves and braking, unless the driver adjusts strategically to adverse conditions, as by reducing speed. Medical disorders such as obstructive sleep apnea (OSA) may further increase the risk of unsafe driving (Pizza et al, 2008; Tregear et al, 2009) and reduce situation awareness and accommodations for altered driving contingencies, such as bad weather and poor sleep. To address these issues, we analyzed three months of speed and accelerometer data obtained from "black box" devices installed in the vehicles of OSA drivers and healthy controls. We compared the naturalistic driving data between groups, and assessed whether the data were associated with visibility information obtained from weather data available from web-based resources.

METHOD

Subjects

Subjects included 45 OSA patients (ages 32 to 59 year, mean±SD of 47.4±7.4) and 21 controls (ages 30 to 59, mean±SD of 46.0±8.4). The OSA subjects were recruited from several sleep clinics in the area, and the controls were chosen to be of similar ages, gender, education, and county of residence as the OSA subjects.

Naturalistic Driving Data Collection

Participants were observed driving their own vehicles for three months using an instrumented vehicle data acquisition system (IV-DAS). The IV-DAS comprises an internal camera cluster (ICC), a central processing unit (CPU), and a network interface box. In addition to trigger-based video recordings, the ICC also collected electronic data on speed, acceleration (longitudinal, lateral, and vertical) and throttle position. This report examined speed, longitudinal acceleration, and lateral acceleration data, updated at 10 Hz. These data were uploaded via cellular technology on a per-drive basis and evaluated within and across drivers.

Preliminary examination of many safety-critical episodes associated with severe accelerations (e.g., magnitudes of 0.35g or greater) showed that these episodes generally lasted 5-10 seconds. Consequently, we chose to summarize the data into 10-second intervals for several driving metrics, including mean speed, SD of speed, SD of lateral acceleration, and SD of longitudinal acceleration. Video data segments were not used in this report, as our focus was on objective measures.

Environmental Data: Visibility

Several local area environmental/weather factors of interest were available online from Weather Underground (www.wunderground.com), which in turn relies on digitized data from National Weather Service's National Digital Forecast Database. From that website, semi-hourly to hourly data were downloaded into comma-separated value files for each day between September 2010 and October 2012. We focused on the "visibility" variable, which was measured in miles, and merged this in with the time-stamped electronic driving data.

Statistical Analysis

Descriptive statistics (mean, SD, minimum, median, and maximum) of visibility and driving measures were calculated for OSA drivers, controls, and across groups. To accommodate the auto-correlation from the longitudinal time series data within drivers, we reduced the data using the "response feature" technique described by Crowder & Hand (1990, p. 11). For comparing groups, we averaged the metrics from multiple 10-second intervals within each subject, which reduced the data down to one row per subject. This allowed us to use Mann-Whitney-Wilcoxon Rank-Sum tests to compare OSA's 45 data points with those of the 21 control subjects.

Simple linear regression analyses tested associations between visibility and driving data in each subject. Wilcoxon Signed-Rank tests assessed if the median regression coefficient was 0. We performed these analyses according to groups (OSA, control, and both groups combined). A similar approach assessed effects of visibility on acceleration, adjusting for mean speed. Here, a multiple linear regression model, including both visibility and mean speed, replaced simple linear regression. To check for interaction between study group and visibility, we also used the Wilcoxon Signed-Rank test to compare coefficients between OSA and control groups. Scatter plots displayed the distribution of estimated regression coefficients.

RESULTS

Table 1 presents the descriptive statistics of visibility, SD of lateral acceleration, SD of longitudinal acceleration, mean speed, and SD of speed within 10-second intervals for all drivers. The 2,181,558 total intervals listed under visibility include approximately 42,000 intervals of driving per subject, or about 4.2 million rows of 10 Hz raw data. As can be seen from the sample size column (N), accelerometer information was available approximately 90% of the time, and speed information was available approximately 80% of the time. Mean visibility was 9.3 miles, based on a scale of 0.2 to 10. Note that the minimum speed was 0.0099 km/hr, rather than absolute zero, indicating a very slight calibration issue.

Table 1. Descriptive statistics of visibility and driving variables, by groups

Variable	Group	N	Mean±standard deviation	Minimum, Median, Maximum
Visibility (miles)	OSA	1540733	9.2843±1.9777	0.2000, 10.0000, 10.0000
	control	640825	9.3317±1.9036	0.2000, 10.0000, 10.0000
	both	2181558	9.2982±1.9563	0.2000, 10.0000, 10.0000
SD of Lateral Acceleration (g forces)	OSA	1384794	0.0245±0.0265	0.0012, 0.0146, 0.4895
	control	610098	0.0278±0.0304	0.0018, 0.0158, 0.3751
	both	1994892	0.0255±0.0278	0.0012, 0.0150, 0.4895
SD of Longitudinal Acceleration (g forces)	OSA	1411264	0.0284±0.0278	0.0018, 0.0172, 0.4808
	control	616698	0.0306±0.0281	0.0018, 0.0197, 0.3379
	both	2027962	0.0291±0.0279	0.0018, 0.0180, 0.4808
Mean Speed (km/hr)	OSA	1230620	60.2736±37.1795	0.0099, 55.3663, 149.1980
	control	558710	59.7273±36.5353	0.0099, 54.9109, 145.2772
	both	1789330	60.1030±36.9804	0.0099, 55.2277, 149.1980
SD of Speed (km/hr)	OSA	1194728	4.2899±5.6672	0.0995, 1.9877, 88.8367
	control	536873	3.6560±4.3406	0.0995, 1.9278, 65.7168
	both	1731599	4.0934±5.2997	0.0995, 1.9677, 88.8367

Table 2 shows descriptive statistics of data, averaged within subjects. P-values showed no differences between groups. Table 3 shows descriptive statistics of the linear regression coefficients within each subject before and after adjusting for mean speed, and the P-value for whether the median coefficient is 0. Unadjusted analyses showed significantly less lateral variability under reduced visibility in the control group (p=0.0232), and significantly slower driving under reduced visibility (p=0.0272 for both groups combined). After adjusting for mean speed, there was less variability in lateral acceleration, longitudinal acceleration, and speed under reduced visibility, within each group and across groups. Hence, drivers appear to execute tighter vehicular control when visibility is lower, even after accounting for slower speeds. In the adjusted analyses, the observed mean coefficients for the control group were higher than for the control groups, but none of these differences was significant. Nevertheless, the data suggest that the relationship between visibility and driving may be weaker in the OSA subjects, possibly due to impaired adaptive strategies.

Table 2. Descriptive statistics of driving measures, with Wilcoxon rank-sum P-values comparing groups

Variable	Group	N	Mean±standard deviation	Minimum, Median, Maximum	P-value
Visibility (miles)	OSA	45	9.2208±1.0147	3.6746, 9.4524, 10.0000	0.6897
	Control	21	9.3663±0.3700	8.5748, 9.4421, 9.8362	
	Both	66	9.2671±0.8624	3.6746, 9.4450, 10.0000	
SD of Lateral Acceleration (g forces)	OSA	45	0.0258±0.0040	0.0180, 0.0252, 0.0357	0.1198
	control	21	0.0280±0.0062	0.0147, 0.0278, 0.0422	
	both	66	0.0265±0.0049	0.0147, 0.0260, 0.0422	
SD of Longitudinal Acceleration (g forces)	OSA	45	0.0303±0.0062	0.0162, 0.0303, 0.0426	0.7937
	control	21	0.0306±0.0065	0.0145, 0.0310, 0.0417	
	both	66	0.0304±0.0063	0.0145, 0.0304, 0.0426	
Mean Speed (km/hr)	OSA	45	57.4305±13.4432	30.2789, 58.0092, 88.0350	0.8364
	control	21	57.7593±13.8019	34.8906, 58.7607, 78.1151	
	both	66	57.5351±13.4525	30.2789, 58.3850, 88.0350	
SD of Speed (km/hr)	OSA	45	4.6043±3.0965	2.7512, 3.7402, 21.4890	0.5539
	control	21	3.6987±0.7278	1.6771, 3.8110, 4.8018	
	both	66	4.3161±2.6142	1.6771, 3.7541, 21.4890	
Age (years)	OSA	45	47.3778±7.3586	32.0000, 48.0000, 59.0000	0.3965
	control	21	45.6667±8.4044	30.0000, 46.0000, 59.0000	
	both	66	46.8333±7.6833	30.0000, 48.0000, 59.0000	

Table 3. Descriptive statistics for linear regression coefficients of visibility predicting four outcomes, with P-values testing median coefficients being equal to 0, unadjusted and adjusted for mean speed

			Unadjusted		Adjusted for Mean Speed	
Outcome	Group	N	Mean±standard deviation	P-value	Mean±standard deviation	P-value
SD of Lateral Acceleration	OSA	45	1.10E-04±1.05E-03	0.4974	2.65E-04±1.34E-03	0.0340
	Control	21	2.56E-04±4.67E-04	0.0232	3.54E-04±5.06E-04	0.0008
	Both	66	1.57E-04±9.03E-04	0.0704	2.93E-04±1.13E-03	0.0004
SD of Longitudinal	OSA	45	2.07E-05±8.56E-04	0.3326	2.73E-04±7.67E-04	0.0086

			Unadjusted		Adjusted for Mean Speed	
Outcome	Group	N	Mean±standard deviation	P-value	Mean±standard deviation	P-value
Acceleration	Control	21	2.33E-04±5.26E-04	0.0663	4.35E-04±6.41E-04	0.0009
	Both	66	8.82E-05±7.68E-04	0.0736	3.24E-04±7.28E-04	<0.0001
Mean Speed	OSA	45	6.26E-01±2.65E+00	0.0863	NA	NA
	Control	21	3.83E-01±1.49E+00	0.1536	NA	NA
	Both	66	5.49E-01±2.34E+00	0.0272	NA	NA
SD of Speed	OSA	45	5.86E-02±3.44E-01	0.8185	3.81E-02±1.82E-01	0.0190
	Control	21	1.61E-02±1.06E-01	0.0386	3.54E-02±9.52E-02	0.0018
	Both	66	4.51E-02±2.90E-01	0.3101	3.72E-02±1.59E-01	0.0002

Figure 1 shows the scatter plot of within subject-regression slopes for modeling SD of lateral and longitudinal accelerations versus subject index, after adjusting for mean speed. Note that the majority of OSA and control drivers had positive slopes, with a higher portion of positive slopes for control subjects.

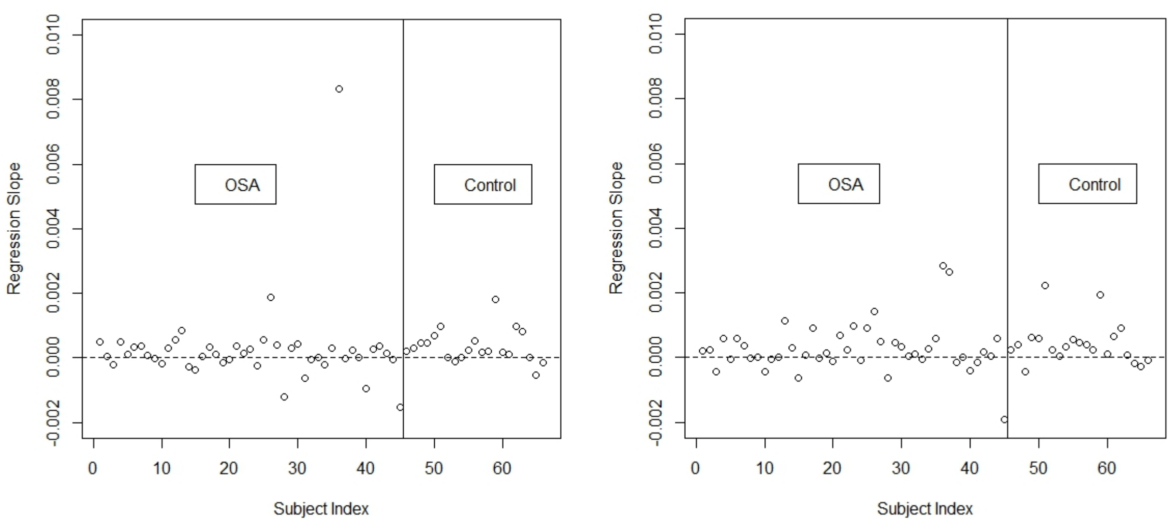

Figure 1. Scatter plots of within subject regression slopes for modeling SD of lateral (left) and longitudinal (right) acceleration, adjusted for mean speed

The method of reducing the data to assess the effects of visibility provides a template for analyzing the effects of many other environmental factors on driving behavior. For example, we applied the same method to examine the effects of wind speed on driving behaviors. Table 4 presents the descriptive statistics of wind speed averaged over all 10-second intervals for all drivers in each group or both, while Table 5 shows descriptive statistics of wind speed, averaged within subject. Note that P-values showed no differences between groups.

Table 6 shows descriptive statistics (mean and SD) of all linear regression coefficients within each subject before and after adjusting for mean speed, and the P-value for whether the median coefficient is 0. Unadjusted analyses showed a tendency towards more speed variability under higher wind speed in the control group (p=0.0511) and in both groups combined (p=0.0900), while there was a tendency towards more longitudinal acceleration variability in both groups combined (p=0.0875). After adjusting for mean speed, there was more variability in longitudinal acceleration under higher wind speed in each group and in both groups combined. There was also more lateral variability under higher wind speed in the control group and in both groups combined, and more speed variability under higher wind speed in both groups combined. There did not appear to be trends of the coefficients being between groups. Hence, OSA apparently does not affect the adaptive strategy for driving when the wind speed is higher.

Table 4. Descriptive statistics of wind speed, by groups

Variable	Group	N	Mean±standard deviation	Minimum, Median, Maximum
Wind Speed (miles per hour)	OSA	1367249	10.1685±4.8638	3.5000, 9.2000, 33.4000
	control	562816	10.1520±4.8263	3.5000, 9.2000, 33.1000
	both	1930065	10.1637±4.8529	3.5000, 9.2000, 33.4000

Table 5. Descriptive statistics of subject means of wind speed, with Wilcoxon rank-sum P-values comparing groups

Variable	Group	N	Mean±standard deviation	Minimum, Median, Maximum	P-value
Wind Speed (miles per hour)	OSA	45	10.0690±1.5456	7.1046, 10.1902, 14.0971	0.9014
	Control	21	10.0463±1.2095	7.1856, 10.3310, 11.4928	
	Both	66	10.0618±1.4378	7.1046, 10.2489, 14.0971	

Table 6. Descriptive statistics for linear regression coefficients of wind speed predicting four outcomes, with signed-rank P-values testing median coefficients being equal to 0, unadjusted and adjusted for mean speed

Outcome	Group	N	Unadjusted		Adjusted for Mean Speed	
			Mean±standard deviation	P-value	Mean±standard deviation	P-value
SD of Lateral Acceleration	OSA	45	-6.65E-06± 3.00E-04	0.6367	4.12E-05± 2.17E-04	0.2810
	Control	21	4.35E-05± 2.16E-04	0.1873	4.90E-05± 1.44E-04	0.0466
	Both	66	9.31E-06± 2.76E-04	0.2573	4.37E-05± 1.96E-04	0.0443
SD of Longitudinal Acceleration	OSA	45	3.46E-05± 3.35E-04	0.2246	8.58E-05± 1.74E-04	0.0017
	Control	21	6.29E-05± 2.93E-04	0.2688	7.37E-05± 8.97E-05	0.0006
	Both	66	4.36E-05± 3.21E-04	0.0875	8.20E-05± 1.51E-04	<0.0001
Mean Speed	OSA	45	1.06E-01± 1.04E+00	0.8286	NA	NA
	Control	21	-1.48E-02± 7.94E-01	0.4477	NA	NA
	Both	66	6.74E-02± 9.61E-01	0.5586	NA	NA
SD of Speed	OSA	45	1.76E-02± 1.07E-01	0.3755	1.30E-02± 5.61E-02	0.2203
	Control	21	1.13E-02± 3.46E-02	0.0511	7.00E-03± 1.96E-02	0.0995
	Both	66	1.56E-02±9.03E-02	0.0900	1.01E-02± 4.75E-02	0.0348

DISCUSSION

This study compared OSA and control subjects with respect to naturalistic driving outcome measures and the environment in which they drove, using level of visibility and wind speed as examples. Although OSA and control drivers generally did not differ in simple analyses, most OSA drivers were being treated (with continuous positive airway pressure devices) for most of their 3 months of driving. The results cannot be interpreted as showing that OSA is not a driving safety risk.

Both groups of drivers appeared to adjust to altered visibility conditions. This adaptation was subtle and some did not adapt at all, or adapted in the wrong direction. More sophisticated analyses in this study suggested that control subjects may have adapted better to adverse visibility conditions than did OSA drivers. On the other hand, the relationship between wind speed and driving appeared to be similar in OSA and control drivers.

Future analyses in this project on OSA drivers will examine before vs. after CPAP treatment comparisons, based on electronic driving measures (as used in this report), as well as based on digital video data from on-board cameras. We will further address between-subject and within-subject factors that relate to the degree of adaptation. We will also employ time-series models, not considered in this report, to reduce the data in additional ways. We will also consider other factors, such as recent history of sleep (based on self report and actigraphy assessments), hours of wakefulness, time of driving in relation to circadian cycles, age, and comorbid conditions associated with OSA such as diabetes, cardiac and cerebral microvascular disease.

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