Effect of Chronic Low-Level Exposure to Jet Fuel on Postural Balance of US Air Force Personnel

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This study used the postural stability technique to investigate the neurological effects of cumulative low-level exposure to raw JP-8 jet fuel vapor on aircraft maintenance personnel. All subjects performed two sets of four 30-second postural sway tests. The results of mean cumulative exposure levels (in parts per million ± standard error of mean) were the following: naphthas, 1308 ± 292; benzene, 21.2 ± 5.7; toluene, 23.8 ± 6.1; and m-, o-, p-xylene, 22.7 ± 5.4. Covariate adjusted regression analysis of the exposed group data showed a statistically significant association ($P < 0.05$) between the solvents (benzene, toluene, and xylene) and increased postural sway response. For all solvent exposures, the "eyes closed, on foam" test provided the strongest association between sway length and JP-8 benzene (r^2 range, 0.45 to 0.52), implying subtle influence a vestibular/proprioception functionalities.

JP-8 is the primary jet fuel used by the US Air Force (USAF) and other North Atlantic Treaty Organization (NATO) air forces. Routine operations involve subtle, inhalation exposures of this fuel for associated maintenance personnel. Most jet fuels are kerosene-based, with variable mixtures of the hydrocarbon compounds; included carbon chains may range from C4 to C16. The jet fuel previously used by USAF was known as JP-4. This fuel had added volatile hydrocarbons to improve performance.[1] The current USAF jet fuel, JP-8, is similar to international jet fuel Jet A-1, except that JP-8 includes for additives to meet required military specifications. Aromatic (toluene, xylene, and benzene) hydrocarbon content for jet fuels normally ranges from 5% to 25% by volume, depending on the desired performance characteristics. The average aromatic content for JP-8 jet fuel was 14.5% in a recent USAF survey, with the highest reported as 18.8%.[1–5]

Jet fuel exposure may be associated with adverse health effects to the neurological system. Although very few neurological studies of the effects of jet fuel have been conducted, the central nervous system (CNS) is noted as the primary target of toxicity after acute inhalation.' Short-term exposure to high vapor levels of jet fuel is known to cause staggered gait, slurring of speech, headaches, nausea, and mental confusion.[6] Long-tern effects of JP-4 may include neurological dam-

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Opinions, interpretations, conclusions, and recommendations contained herein are those of the authors and do not reflect the views of the U.S. Air Force.

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age.[6-8] Scandinavian studies by Knave et al[9-11] and Struwe et al[12] are of particular interest because they addressed neurological effects from MC-77 jet fuel (the Swedish military equivalent to JP-4) exposure over a lifetime of work. Their study group consisted of aircraft maintenance workers exposed at 8-hour average exposure levels of between 250 mg/m^3 (30 parts per million [ppm]) and 300 mg/m^3 140 ppm). These studies used a battery of psychological tests, electroencephalograms, reaction time, nerve-conduction velocity, and threshold of vibration sensation measurements. Their investigation revealed significant differences between their exposed and nonexposed groups for psychiatric symptoms, attention, sensorimotor speed, and electroencephalograms. Two quantitative CNS measurements, nerve conduction and vibration sensation, identified smaller nerve action potential and an overrepresentation of higher vibration thresholds of extremities in the exposed group.[9] Several animal exposure studies using mice, rats, monkeys, and dogs were conducted by the USAF for JP-4 jet fuel. Their results indicate neurological effects ranging from "poor coordination and convulsions" (rats) with a 38,000 mg/m^3 (4750 ppm) acute exposure to "quiescent and prostrate" reaction (dogs and monkeys) with up to 5000 mg/m^3 (625 ppm) moderate exposure. The moderate exposure period was 6 hours per day, 5 days per week, over 8 months.[5]

No published research on the chronic neurological effects of low-level exposure to JP-8 jet fuel is available. The acute toxicological effects of JP-8 jet fuel are expected to resemble those of kerosene, a CNS depressant." A 1996 report from the US National Research Council's (NRC) Committee on Toxicology noted the lack of quantitative research on CNS and associated performance measurements of workers with chronic low-level exposure to jet fuel vapors. The NRC report recommended more research using quantitative measurements on the effects of jet fuel vapors to the nervous system.[13] One quantitative method of assessing neurobehavioral effects of exposure to neurotoxic chemicals is the use of quantitative posturagraphy.[14-19]

Postural balance measurement provides a unique "biological marker" of environmental chemical-associated changes in functional aspects of the nervous system. The technique has been tested and validated and found to be sensitive enough to detect significant changes in body balance with a reference solvent (ethanol) level as low as 0.02% blood alcohol level." In a prospective study in our laboratory sponsored by the National Institute for Environmental Health Sciences (NIEHS), the above-mentioned technique has been found to be effective in quantifying postural disequilibrium in children with a known history of lead exposure.[15,20] Results show a significant relationship between postural sway and blood lead levels in these children.") Other studies have been recently completed to determine the effectiveness of the force platform technique for investigating the relationship between postural sway and exposure to other neurotoxic agents such as pesticides[16] and solvents.[19]

The specific aims of the present study were (1) to compare postural balance between a JP-8–exposed USAF population and a nonexposed population, and (2) to determine if there is a relationship between chronic exposure to jet fuel constituents and changes in postural sway.

Methods

Subjects

Individuals selected for the postural sway tests was limited to USAF employees working in JP-8 jet fuel-related occupations for at least six months. The selected work areas included Jet Engine Repair, Jet Engine Test Cell, C-5 Aircraft Fuels Maintenance, and Base Fuels Distribution Center, all of which were reported as having potential jet fuel exposure. To measure an effect size[21] of 0.25, the study required 30 exposure subjects to meet an alpha of 0.05 and beta of 0.20 (80% power) as defined in the study by Dick et al[22] on postural sway testing protocol for neurobehavioral toxicology.

The exposed group consisted of 30 USAF employees at two air bases. This group had a mean exposure period of working in jet fuels–related occupations of 12.0 years and a range of 0.8 to 30 years. Their mean period of exposure to JP-8 jet fuel was 4.56 years. Thirty-seven percent of the exposure group had worked only with JP-8. Three volunteer subjects were excluded from the study: two because of their failure to complete the assessment, and one because of our identifying a disqualifying neurological condition after the assessment was complete. The final sample size ($n = 27$) had a mean age of 37.5 years (range, 13.6 to 57.4 years); 20 were male and seven were female. A group of 25 unexposed subjects with comparable age to the exposed group was used for postural sway comparison. This group consisted of volunteers from the military, the university, and other sources. The group had a mean age of 34.0 years, with a range of between 21.0 to 57.0 years and a gender mix of 14 male and 11 female subjects.

Each subject's physical measurements for weight and height were collected at the time of testing. Subjects also completed health and work history questionnaires. The health questionnaire identified age, sex, race, weekly consumption of alcohol, and daily consumption of caffeine and of cigarettes (Table 1). This questionnaire was also used to collect health history data for identifying factors that may influence postural balance. The work history questionnaire was used to determine "years worked with JP-8" and "total years worked with all jet fuels."

TABLE 1
Demographics Comparison'

Variables	Exposed group [n = 27] [Mean ± (SD)] [Range. minimum − Maximum]	Unexposed group [n = 24 [Mean ± (SD)] (Range, minimum — Maximum]
Age (years)	37.5(±9.3) (24 to 57)	34.0 (±8.3) (21 to 57)
Height (cm)	172.5 (±7.4) (157 to 1831	169.3 (±8.7) (152 to 185)
Weight (kg)	79.6 (±18.6) (50 to 126)	70.5 (±13.2) (52 to 107)
WTHT (kg/cm)	0.46 (±0.10) (0.3 to 0.7)	0.42 (±0.07) (0.3 to 0.6)
Smoke (cigarettes/day)	6.4 (±8.7) (0 ta 20)	1.4 (±3.9) (0 to 16)
Alcohol (drinks/week)	9.3(±18.4) (0 to 84)	0.95 (±1.2) (0 to 5)
Caffeine (drinks/day)	3.3 (±2.6) (0 to 12)	2.1 (±2.0) (0 to 7)

' WTHT, weight-to-height ratio.

Exposure Assessment

The level of jer fuel exposure was characterized using industrial hygiene (IH) techniques. JP-8 exposure assessment involved the collection of IH 8-hour breathing zone samples from each of the subjects. IH monitoring was conducted during two separate 8-hour work periods for each exposed worker. All air samples were collected on charcoal tubes and in accordance with National Institute for Occupational Safety and Health Analytical Methods 1500, 1501, and 1550.[23] Analysis was carried out by gas chromatography with a flame ionization detector (GC/FID) at a nationally certified laboratory. All analysis is reported in the units of parts per million (ppm). The analyte group evaluated in this study included jet fuel and the solvents benzene, toluene, and m-,o-,p-xylene. Jet fuel is reported as naphthas (total hydrocarbon, chains C4 to C16).[4,5]

Three separate exposure periods were used for analysis. These are (1) "TWA-acute," the acute exposure based on 3-hour time weighted average (TWA) air samples for each subject. (2) "Cum JP-8." and (3) "Cum All-JP." The acute exposure period. "TWA-acute," was also used to determine any potential effects from acute exposure prior to testing an the day of the balance rest. Subjects were divided into early and late rest groups. Each subject was assigned a score: (0) for those tested during the first four hours of the work period and (1) for those tested in the last four hours of the work shift. The groups were then compared to determine if any significant difference was present in sway test results. The other exposure periods. "Cum JP-8" and "Cum All-JP," are calculations of cumulative exposure derived from averaging current daily 8-hour samples taken from each subject and using individual dam provided in the work history questionnaires. "Cum JP-8" is the period during which the subjects worked with only JP-8 jet fuel. This period is the most recent exposure work period for all exposure subjects. "Cum All-JP" is total jet fuel exposure and covers all jet fuels (JP-4. JP-5, JP-8) the subjects were exposed to during their USAF careers. Each analyte was assessed for each exposure period by using current exposure levels to estimate prior exposure. This estimation of cumulative exposure is known to be conservative because the previous fuel used, JP-4, had a higher percentage of small carbon-chain solvents than JP-8.[1-8] To ease identification of specific analysis, the results are addressed by exposure period and then analyte type; for example. "Cum JP-8 Benzene" is the analysis of cumulative benzene exposure during the JP-8 work period.

All subjects' cumulative exposures were calculated for their JP-8 and total jet fuel work periods to determine the total ppm of each analyte of exposure. Calculations of cumulative exposure combined individual exposure in units of ppm per hour multiplied by the total number oh hours worked in each cumulative exposure period. The number of hours worked was determined by using actual years worked multiplied by a standard 1800-hour work period per year. The standard work yew hours was determined from the normal annual work period. in terms of hours. for USAF maintenance workers. less normal leave. sick leave. and federal holidays. The number of hours worked was used for the assessment of exposure during the JP-8 work period (Cum JP-8) and the total jet fuel work period (Cum All-JP).

Postural Balance Test

Postural sway measurements were conducted with an Advanced Mechanical Technology. Inc. (AMTI. Watertown, Massachusetts) AccuSway System portable force platform and a Halikan Chaplet System (Halikan. Taiwan. China), NBD 486 laptop computer. This force platform is equipped with "Hall Effect" sensors with a built-in microprocessor to capture signals of forces and moments resulting from these forces. The platform provides direct outputs for forces in the vertical direction (Fz), horizontal directions (Fx and Fy), and moment around the x-axis (lateral), moment around the y-axis (anterior-posterior) and moment around the vertical z-axis.[14] These captured signals are then transferred directly to the microcomputer via an RS-232 serial port. Data were acquired at a 50-Hz sampling rate and were transmitted through the RS-232 interface at 9600 baud. The data were analyzed with the Body Balance Software developed in our laboratory (all rights reserved 1995. by the University of Cincinnati). This software calculates the x-y coordinates of the body's center of pressure for each 30-second test. Total area and length were used to characterize the sway patterns obtained in this study. Total area of sway (SA) is the area enclosed within the envelope of the outer perimeter of the x-y plot of the center of pressure. Total length of sway (SL) is determined by the distance. in centimeters, traversed by the center of pressure during the test period*

The postural sway testing method followed protocol approved by the University of Cincinnati Institutional Review Board. The test indirectly measures the effect of proprioceptive, visual, and vestibular systems on the maintenance of postural balance. As postural control systems are compromised, changes in the sway pattern can be quantified through mapping of changes in postural sway. For the postural sway tests, all subjects performed a series of four separate 30-second tests in two separate trials (Trial 1 and Trial 2). For Trial 2, the tests were conducted in the reverse order. The tests included the following:

EO: eyes open, standing on *bare platform.* This tested the collective effect of the visual, proprioceptive, and vestibular systems controlling postural sway.

EC: eyes closed standing on bare platform. This test removed the visual *system* and therefore tested the proprioceptive and vestibular systems.

FO: eyes open, standing on a piece of 4-inch foam placed over the platform. This test modified the proprioceptive system and therefore tested the visual and vestibular systems.

FC: eyes closed. standing on a piece of 4-inch foam placed over the platform. This test removed the visual system and modified the proprioceptive system, which allowed the vestibular system to act as the primary control of postural sway.[20]

Exact foot placement was maintained between tests by drawing an outline of the subject's feet on a paper taped onto the force platform.[14,18] The subject's foot angle was maintained at 30 degrees. This angle was determined by use of a wedge during alignment of feet prior to testing.

Data Analysis

All analysis used the mean SA and SL for each test from the two balance trials (1 and 2) conducted by the subjects. Analysis of variance (ANOVA) and Student *t* test were used to compare the sway variables of the exposure group to sway variables of the control group. Pearson product moment correlations were used to identify significant confounders and covariates. A linear multiple regression analysis using a backward elimination of covariates was used to determine the relationship between jet fuel exposure and postural sway variables.[14,19,24] The Statistical Analysis System (SAS) software package[24] was used for data analysis.

The dependent variables used to quantify postural sway were mean SA and mean SL for each test. For the statistical analysis, SA and SL variables were transformed to their natural logarithm. The independent variables used were exposure periods (TWA-acute, CumJP-8, Cum All-JP) for each reported analyte (ppm), age (years), weight to height ratio (WTHT), gender, alcohol consumption (12-ounce beer equivalent drinks per week), caffeine consumption (8-ounce drinks per day), and smoking (cigarettes per day). WTHT was used in place of weight and height individually because these covariates are highly correlated." Selection of these variables were based on those found to be significant in previous studies.[14,19,25]

The bivariate correlation investigated associations between independent and dependent variables and between analytes within the independent exposure variables TWA-acute, CumJP-8, and Cum All-JP. A non-zero correlation was reported as statistically significant at $P \leq 0.10$. Potential confounders were defined as variables with non-zero correlation with the exposure variables and with the sway variables. Covariates were identified as variables with non-zero correlation with the sway variables only.

The regression model's backward elimination method systematically eliminates the independent variables with the least predictive power. until all remaining variables have a P value of ≤ 0.1. The exposure variable was forced to remain in the model regardless of its P value. Covariates that remained after backward elimination are identified as cofactors of the regression model. Because (by hypothesis) sway is expected to increase with increasing exposure. a one-tailed alpha of 0.05 was used for statistical inference. The initial linear regression models for SA and SL, with b0 to b7 as the regression coefficients, were the following:

Natural lag of dependent sway variable =

$$\text{b0} + \text{b1(solvent exposure)} + \text{b2(gender)} + \text{b3(WTHT)} + \text{b4(age)} + \text{b5(alcohol)} + \text{b6(caffeine)} + \text{b7(smoking)}.$$

To test the potential effects of acute exposure that may have occurred during the day of testing. a Student t test was conducted for statistical comparison of subjects tested early in the day and subjects tested after completing more than half of the work shift. This comparison between the time a subject was tested and results of the subject's balance test was used to identify any influence on sway results caused by acute exposure prior to testing.

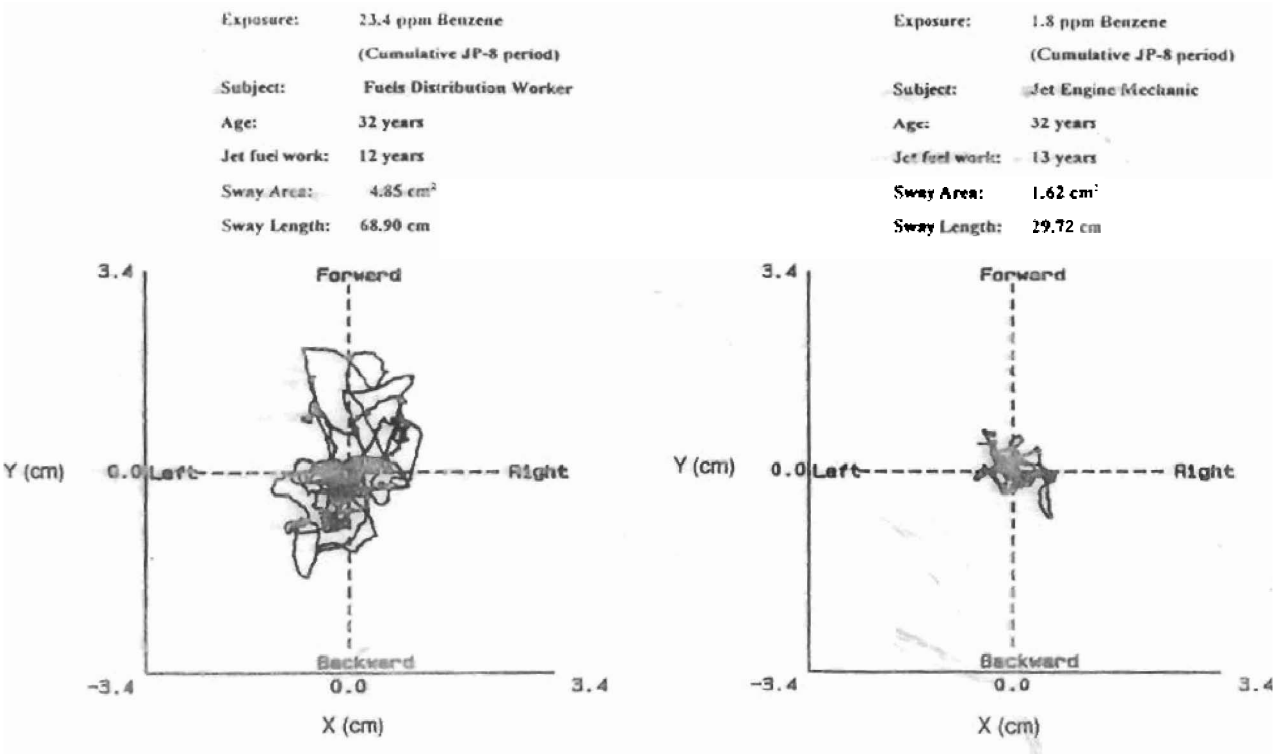

Fig. 1. Comparison of two exposure subjects, EC test (eyes closed, standing on plate).

shows a positive correlation between cumulative exposure and increased sway. In comparison to SL, the model for SA was significant for the EC test only (Table 3). For the TWA benzene and All-JP benzene. SL regression models showed statistically significant r^2 for the FO (r^2 = 0.61 and 0.57) and the FC (r^2 = 0.48 and 0.45) tests only. The SA model was statistically significant for TWA benzene (r^2 = 0.19) and All-JP benzene (r^2 = 0.21) for the FC test only. For the jet fuel constituents of toluene and xylene, the SA regression models showed statistically significant r^2 values for FC tests (r^2 = 0.21 All-EP toluene; r^2 = 0.11 JP-8 xylene; r^2 = 0.22 All-JP xylene). FO test (r^2 = 0.20 TWA xylene), and EC rests (r^2 = 0.13 JP-8 toluene; r^2 = 0.16 JP-8 xylene). The statistically significant SL models were for FC tests (r^2 = 0.46 All-JP toluene; r^2 = 0.48 JP-8 xylene, and r^2 = 0.47 All-JP xylene), FO test (r^2 = 0.52 All-JP toluene). EC tests (r^2 = 0.13 JP8 toluene; r^2 = .15 JP8 xylene), and EO test (r^2 = 0.51 JP8 xylene). No statistically significant relationship was noted between naphtha exposure and postural sway.

Several cofactors were identified in the regression modeling: (1) WTHT, which had a statistically significant association with 54 of the 96 total sway tesr conditions. Notable in this result is that WTHT is associated in 36 of 48 test conditions for SL—all 12 unassociated conditions were for the EC test; (2) gender and caffeine for Cud-8 benzene EC test for SL; and (3) age for 10 of the 12 FO tests for SL and all four CumJP-8 solvent-exposure FC tests for SL. Consistently through the regression models, the WTHT cofactor was in the negative direction, whereas all other coefficients were in the positive direction. Because WTHT is not related to exposure, it should not change modeled exposure effects. Smoking did not have a statistically significant association with the sway variables.

No statistically significant difference in SA and SL was noted between the subjects tested early during the work day and those subjects tested later.

Discussion

This study demonstrated a positive relationship between changes in postural balance variables and exposure to constituents of jet fuel under a number of postural balance test conditions. An increased exposure level showed an increase in postural sway, implying poorer postural balance. An overview of the regression models implicates Cum JP-8 benzene as the most significant exposure variable affecting postural balance. Of the two dependent variables, SA and SL, regression models for SL had more statistically significant results ($P \leq 0.05$) and much higher coefficients of determination (r^2) ranging from 0.13 to 0.64 (for SA, statistically significant r^2 ranged between 0.11 and 0.22) for all exposure periods. SL models for Cum JP-8 xylene were significant in three of four sway tests. A review of regression models of SL for the three exposure periods, TWA-acute, Cum JP-8, and Cum All-JP, indicates that the Cum JP-8 period showed the most (12 of 32 models) statistically significant re-

TABLE 3

Cum JP-8 Benzene Regression Models (n = 27)

Test	Dependent Variable*	Independent Variable	Parameter Estimate	Standard Error	P Value (one-tailed)	Model r^2
EO						
	SA	Intercept	0.78	0.1[illegible]		0.08
		Exposure	0.02	0.01	0.08	
	SL	Intercept	4.35	0.15		0.56
		Exposure	0.01	0.004	0.01	
		WTHT	−1.43	0.31	0.0001	
EC						
	SA	Intercept	1.05	0.10		0.19
		Exposure	0.03	0.01	0.01	
	SL	Intercept	3.95	0.09		0.44
		Exposure	0.02	0.01	0.0005	
		Gender	−0.17	0.09	0.03	
		Caffeine	0.03	0.62	0.04	
FO						
	SA	Intercept	2.01	0.39		0.22
		Exposure	0.013	0.01	0.13	
		WTHT	−1.80	0.81	0.02	
	SL	Intercept	4.30	0.15		0.64
		Exposure	0.01	[illegible]	0.0[illegible]9	
		Age	0.008	0.003	0.007	
		WTHT	− 160	1.29	0.0001	
FC						
	SA	Intercept	1.72	0.10		0.08
		Exposure	0.016	0.01	0.08	
	SL	Intercept	4 40	[illegible]		0.52
		Exposure	0.014	[illegible]	0.009	
		Age	0.014	0.004	0.003	
		WTHT	−1.35	0.42	0.002	

* Dependent variables are natural log transformed.

sults. One other result of note was that the regression models of SA and SL with naphthas were not found to be statistically significant for any test in any exposure period.

This study examined possible associations between exposure to constituents of jet fuel, and a total of four correlated outcome measures for SA and for SL. To reduce the likelihood of finding a false-positive between exposure and sway, a Bonferroni correction was applied to all the regression models. By applying Bonferroni corrections to Table 3, the conclusions of significant findings remain unchanged in all five of the statistically significant test results. Bonferroni corrections did not affect conclusions in two of seven statistically significant test results for SA and nine of the 15 statistically significant test results for SL from all of the solvents analyzed. Consequently, sway relationships with P values between 0.05 and 0.0125 are to be interpreted as only suggestive of significant effects. The conclusion after Bonferroni corrections is that cumulative benzene exposure maintained the strongest association with increased SL.

The comparison of sway stabilographs (Figure 1) for low- and high-exposure subjects suggest that there is a cumulative effect of neurotoxic solvents on postural sway. The exposure summary in Table 2 provides an interesting comparison of how different the solvent exposure levels can be, even when total hydrocarbon exposure levels are relatively comparable. This difference in cumulative solvent level may be explained by the high level of exposure that subjects can receive when opening storage tank. Small carbon chain ($C<8$) organic solvents evolve considerably faster than total hydrocarbons to fill the vacant "head space" of storage tanks.[26] Jet fuel jobs involved with opening closed head space areas, such as checking the level of a fuel storage tank, may receive a much higher exposure to the smaller-chain carbon solvents.

The regression models implicate potential functional impairment of postural balance from cumulative exposure to low levels of solvents. The strongest effect was seen in the Cum *JP-8* benzene exposure period regression model. The regression models for SL for all four test conditions were statistically significant. Among all SL models, the highest and the second highest r^2 values were observed for the FO (r^2 = 0.64) and the FC (r^2 = 0.52) tests, respectively. Increases in sway measured during these tests imply that functional abilities of proprioceptive and vestibular

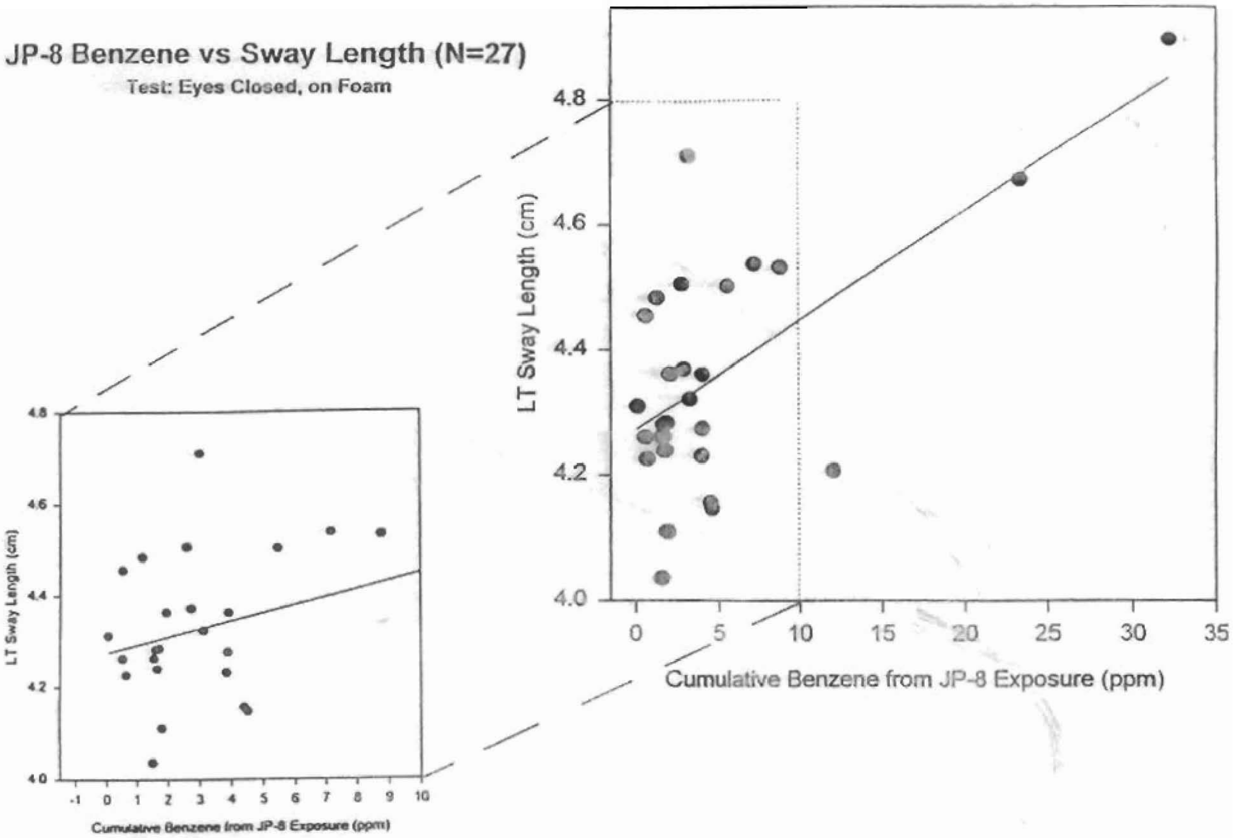

Fig. 2. A regression plot of covariate adjusted sway length (SL) and cumulative JP-8 benzene (cum JP-8 benzene) exposure value for the eyes closed, on foam test.

pathways are possibly affected.[14,18] This result is consistent with the findings of the Kuo et al[19] study of sewer workers, which naed a positive correlation between postural sway and organic solvent exposure for the EC, FO, and FC tests.

Xylene and toluene regression models of SL were also statistically significant for cumulative periods, but not for acute TWA periods. The xylene models were similar to the benzene models and had the most statistically significant effect of Cum *JP-8* period on *SL* for the EO *test* and the FC test. Only FC was statistically significant in the Cum All-JP period. The xylene model was only statistically significant in the TWA-acute period for SA in the FO test. The lack of an acute effect is consistent with the findings of the Savolainen et al[26] study, in which subjects exposed to 100 to 400 ppm m-xylene for four hours, which found no statistically significant increase in postural sway.

The difference in outcome of the solvent models during different exposure time periods and the strength of these correlations may implicate individual differences such as absorption rates, metabolism, mute of exposure, or other factors that affect bow each solvent interacts with the afferent systems and thereby cause degradation of balance. The outcome of these models does support the theory of a low-dose cumulative effect of neurological toxicants, as opposed to an acute effect.[12,25,27]

This outcome may be contrasted to the findings of Bergin et al[28] study of body sway and vibration and the Knave et al[9] study of jet fuel exposure. The Bergin et al study used a similar force-plate system and proprioceptive challenge tests for vision (EC, FC), a compliant surface (FO, FC) to measure postural balance, and three different tests for vibration perception. Bergin et al showed how subjects with a higher vibration threshold sway more than those with lower thresholds, implying potential modification of the peripheral nervous system. Their study noted *that* when the proprioceptive system is stressed, small differences in vibration perception threshold in the normal population may become important far postural sway control. The Knave et al[9] study identified signs and symptoms that were possibly indicative of polyneuropathy in a population routinely exposed to jet fuel. This finding included identification of *an* overrepresentation of higher vibration thresholds of the extremities in the exposed pup. Our study essentially provides further support to the findings in these studies but with a shorter exposure period than that observed in the studies by Bergin et al[28] and Knave et al.[9] The strongest correlation between routine low-level exposure to jet fuel and increased sway identified in our study was found for the tests thar challenge the proprioception system (EC, FO, and FC). Because the mean age of our study population is considerably younger than that of the subjects in the studies by Bergin et al and Knave et al, the effect from cumulative exposure appears to be manifested earlier rhan was expected. The immediate implication of these results is that if jet fuel does reduce proprioception functionality, then this could be a significant safety factor for personnel working around aircraft in dark areas, or on slippery (oil, water, ice) or compliant surfaces (mud, soft soil). The long-term implication of continued routine exposure is an increased risk of degrading specific neurological functions.

The postural balance rest provides a good preclinical noninvasive method to identify the onset of long-term CNS degradation. Postural sway testing may be used as a preclinical tool to monitor changes in postural balance, just as an audiometry program monitors changes in hearing threshold. A system by which annual postural sway measurements are compared to a baseline measurement could provide occupational medicine providers with a method of measuring the effects of neurotoxic chemicals on the workforce. There is published work that indicates a need for associating the two types of preventive medicine tools. Findings from the Morata et al[29] study noted a positive association between occupational exposure to solvents and hearing disorders and a specific effect when these are combined with noise. Odkvist et al[27] identified vestibular-ocular motor damage from solvent and jet fuel exposure, and Bergin et al[28] used an audiometer's bone vibrator to assess proprioceptive function. It is apparent that postural balance measurements may be useful in combination with a hearing conservation program to better quantify the synergistic effects of occupational noise and solvent exposure on an at risk population.[6]

In addition to monitoring the postural balance effects of neurotoxic solvents on maintenance workers, the balance test may be useful for neurobehavioral monitoring of USAF flight crews. Pilots must have excellent vestibular-ocular motor function to operate aircraft safely. However, this group has potential for significant pressure changes associated with high-altitude flight and receives routine low exposure to jet fuels and jet engine exhaust (personal communication with USAF Flight Surgeon concerning jet fuel exposure to pilots, Henderson J. USAF Medical Center, Wright-Patterson AFB, OH, 1996). Two studies emphasized the importance of these exposure factors. The first is the study by Adolfson et al[30] on atmospheric pressure changes on divers, which noted an effect on the postural balance portion of the vestibular system with significant pressure change. The other study, by Odkvist et al,[27] researched solvent effects on the vestibular-oculomotor system and noted a 50% abnormal response in jet fuel–exposed subjects for the visual suppression test (tracking of nonperiodic targets). These findings become even more important when viewed in the context of flying at supersonic speed, where minute degradation to any neural pathway could be catastrophic. They also support the use of balance testing as a quantitative measurement during routine medical examination. Medical services supporting flight crews may also find balance testing useful as a tool to measure recovery prior to medically qualifying a pilot to flying status. In situations in which a crewmember is grounded because of some type of neurological insult, such as acute high exposure to a neurotoxic solvent in which recovery cannot be easily measured through subjective tests,[6] the use of a quantitative balance test to compare against a baseline measurement would prove useful for determining recovery.

In summary, this study showed an increase in postural sway from relatively low TWA exposure levels over moderate work periods of 5 years for cumulative JP-8 exposure to 12 years' cumulative exposure to all jet fuels. Mean TWA exposure levels of JP-8 constituents were significantly below ACGIH threshold limit values and lower than other exposure studies previously mentioned (references 6, 9, 12, 31–34; personal communication concerning jet fuel feasibility study, with Lemasters G, and Simpson S. Department of Environmental Health, University of Cincinnati, Ohio, 1996; and personal communication concerning evaporative aspects of JP-8 in vacant head space, with USAF toxicologist Mattie D, Armstrong Lab/Occupational Environmental Toxicology, Wright-Patterson AFB, OH, 1996). The regression models indicate that chronic low-level solvent exposure has a major influence on postural balance. The implication is that routine low-level doses of these neurotoxic solvents has a cumulative effect. This result may provide an early indication of potential long-term neurological health effects, such as degraded nerve conduction, changes in vibration sensation, or psychoorganic syndromes as noted in the Scandinavian studies.[9–12,31]

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