Sound exposures and hearing thresholds of symphony orchestra musicians

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(Received 28 March 1990; accepted for publication 21 January 1991)

To assess the risk of noise-induced hearing loss among musicians in the Chicago Symphony Orchestra, personal dosimeters set to the 3-dB exchange rate were used to obtain 68 noise exposure measurements during rehearsals and concerts. The musicians' L_{eq} values ranged from 79–99 dB A-weighted sound pressure level [dB(A)], with a mean of 89.9 dB(A). Based on 15 h of on-the-job exposure per week, the corresponding 8-h daily L_{eq} (excluding off-the-job practice and playing) ranged from 75–95 dB(A) with a mean of 85.5 dB(A). Mean hearing threshold levels (HTLs) for 59 musicians were better than those for an unscreened nonindustrial noise-exposed population (NINEP), and only slightly worse than the 0.50 fractile data for the ISO 7029 (1984) screened presbycusis population. However, 52.5% of individual musicians showed notched audiograms consistent with noise-induced hearing damage. Violinists and violists showed significantly poorer thresholds at 3–6 kHz in the left ear than in the right ear, consistent with the left ear's greater exposure from their instruments. After HTLs were corrected for age and sex, HTLs were found to be significantly better for both ears of musicians playing bass, cello, harp, or piano and for the right ears of violinists and violists than for their left ears or for both ears of other musicians. For 32 musicians for whom both HTLs and L_{eq} were obtained, HTLs at 3–6 kHz were found to be correlated with the L_{eq} measured.

PACS numbers: 43.50.Qp, 43.50.Yw, 43.66.Ed, 43.75.Cd

I. INTRODUCTION

In response to musicians' concerns about the possibility of developing noise-induced hearing loss, sound exposure measurements and hearing threshold data were obtained for musicians in the Chicago Symphony Orchestra to determine whether the players face a significant risk of developing noise-induced permanent threshold shift (NIPTS) in their profession. Two approaches were taken to determine the risk of hearing damage.

(1) Sound exposures for musicians were measured and evaluated in terms of their potential to cause NIPTS, according to the model presented in ISO 1999 (1990).

(2) Measured hearing thresholds for musicians were compared to reference age-effect populations to determine whether the group of musicians showed any more hearing loss than expected from aging and nonoccupational hearing hazards.

The study did not attempt to address the issue of annoyance among musicians and/or players' difficulty in monitoring their own instruments during periods of high sound levels on stage. Neither did it attempt to address the occurrence of tinnitus or any other auditory dysfunctions except elevated pure tone thresholds.

II. RELEVANT LITERATURE

A. Sound exposures

Both the instantaneous sound levels measured for a musician and the resulting equivalent continuous sound level (L_{eq}) for the measurement period depend on the instrument played and the music being performed, as well as the position of the musician on the stage in relation to other players. The microphone location is also important, especially in instances where one ear receives a higher sound exposure either from the player's own instrument (such as the left ear for a violinist) or from other instruments. Literature reports of sound levels and exposures of musicians have not always described their measurement conditions adequately to permit comparison of results among authors.

Westmore and Eversden (1981) recorded A-weighted sound pressure levels [dB(A)] using a tripod-mounted sound level meter at various stage positions during different symphonic works; levels exceeded 90 dB(A) 17.5% of the playing time, but no L_{eq} values were given. Jansson and Karlsson (1983), using tripod-mounted microphones, measured L_{eq} values 93.1 dB(A) for heavy exposure positions and 88.9 dB(A) for light exposure positions during performances. Axelsson and Lindgren (1981) reported L_{eq}'s measured using tripod-mounted microphones during performances. The L_{eq}'s for concerts ranged from 83.3 to 91.6 dB(A). Based on a workweek with 25 h of rehearsal and performance, the estimated daily equivalent L_{eq}'s for musicians ranged from 78.5 dB(A) to 88.4 dB(A). In a contract report, Camp and Horstman (1987) described personal dosimetry results on musicians using the 5-dB exchange rate specified by OSHA; the average L_{osha} values ranged from 82.4 dB(A) for bass players to 96.0 dB(A) for horn players during rehearsals and performances of the Gotterdammerung from Wagner's Ring Cycle, a work which contains excessively loud passages. (Note: In the current study the L_{osha} is estimated to be about 2 dB lower than the L_{eq}.) Woolford *et al.* (1988) summarize a dosimetry study of 30 musicians by Schacke (1987). Average sound levels for brass and for woodwind players both ranged from 87–96 dB(A), with the exposure for a typical day calculated as an 8-h L_{eq} of 87.7 dB(A). The ranges of average sound levels were lower for violins and violas [86–93 dB(A)] and for cellos and basses [81–87 dB(A)].

In summary, the available studies on orchestral sound exposures indicate that at least some orchestra members have typical daily 8-h L_{eq} values exceeding 85 dB(A) from their on-the-job playing time alone. Therefore, it would be expected that some musicians may face a risk of hearing damage from on-the-job noise, depending on their long term noise exposure and their own susceptibility to noise-induced hearing loss. The predicted risk would increase for some players if the total noise exposure were calculated to include off-the-job exposures such as solitary practice, teaching student musicians, and moonlighting in other musical groups.

B. Hearing levels

Another way of assessing the risk of NIPTS among musicians is to evaluate the hearing threshold levels (HTLs) for orchestra members. If musicians as a group do not show more hearing loss than expected for their age, then the risk of NIPTS for their profession may be assumed to be insignificant.

Westmore and Eversden (1981) obtained audiograms for 34 orchestral musicians and reported that 34% of the ears showed audiometric patterns consistent with noise-induced hearing loss (not defined, but assumed to mean a notched shape); however, the degree of loss was slight. Rabinowitz *et al.* (1982) reported audiometric results for 110 orchestral musicians. Only 52 individuals had any HTLs exceeding 20 dB; based on history information, the authors concluded that the hearing loss could be attributed solely to music in 22 musicians, while it was impossible to evaluate the proportion of music-related loss in the other 30 cases. Johnson *et al.* (1985, 1986) measured hearing thresholds of 60 orchestra members; they reported the average differences between the measured thresholds and the expected age-effect thresholds from Spoor's (1967) data as less than 10 dB, but they alluded to a notch shape with poorer HTLs at 6 kHz than 8 kHz. In a pilot study of the hearing thresholds of 13 orchestral musicians, Woolford *et al.* (1988) found HTLs no worse than 25 dB in half the ears, while 11 ears showed sensorineural loss and 2 ears showed conductive loss.

Axelsson and Lindgren (1981) studied the hearing of 139 musicians, many of whom had previous military noise exposure. Binaurally averaged hearing thresholds showed a notched shape with the poorest threshold at 6000 Hz, but the average degree of loss was small. However, these averages might have been much higher if thresholds had not been measured down to − 15 dB. The greatest hearing losses were found in musicians playing bassoon, horn, trumpet, and trombone. String players showed better average hearing than expected for their age in the right ear, but left ear HTLs were poorer. Karlsson *et al.* (1983) measured HTLs (down to a minimum of + 10 dB) for 392 musicians. Median and 25th percentile data were equivalent to Spoor's (1967) reference values, indicating no sign of NIPTS for the overall population. However, median data did show a 6-kHz dip in the audiometric configuration. Jansson *et al.* (1986) attempted to reconcile the differences in findings between the two preceding Swedish studies. Through reanalysis of the data, the researchers agreed that although median HTLs of musicians were close to ISO 7029 (1984) presbycusis reference data, a higher percent of individual musicians did show poor HTLs (worse than the 0.05 fractile of the reference data) than in a non-noise-exposed population.

Ostri *et al.* (1989) measured the HTLs of 96 musicians. Half the males and 13% of the females showed notched audiograms. The 75th percentile, median, and 25th percentile HTL data for musicians were poorer by up to 10–15 dB than matching percentiles for ISO 7029 presbycusis reference data at 3–8 kHz. The median audiogram for males showed a maximum dip at 6 kHz. Violinists showed significantly poorer hearing in the left ear than in the right.

To summarize the available studies of musicians' hearing, all investigators have found hearing loss in a pattern consistent with noise-induced hearing damage in some players, but the majority of musicians show hearing levels within the normal range. This consistency suggests that the degree of hearing hazard is low, but that susceptible individuals may be at risk. Results show greater hearing loss in the left ear than in the right ear for violinists, indicating that the apparent NIPTS is related to the greater exposure of the left ear.

III. METHOD

A. Subjects

All members of the Chicago Symphony Orchestra were encouraged to participate in the study by voluntarily signing up to take an audiogram and/or to wear a dosimeter to measure sound exposure during a rehearsal or performance. Audiograms were given prior to the orchestra's playing in order to avoid contamination of HTLs by temporary threshold shift. Of the approximately 100 musicians in the orchestra, 59 voluntarily received audiograms.

A total of 68 dosimetry samples were obtained on 44 musicians. Data were collected during two separate weeks, several months apart, in order to increase the variety of musical selections being rehearsed and performed. Two dosimeters were placed in different positions on the stage during each measurement period as a check on the personal dosimetry readings, but these results were not included in the analysis since they were not actual exposure measurements for individual players.

B. Instrumentation

Portable audiometers were used with Etymotic Research ER-3A insert earphones in order to allow testing in available quiet rooms in Orchestra Hall. The calibration of each audiometer was checked with a specific pair of ER-3A insert earphones according to the interim calibration data in ANSI S3.6-1989 to obtain exact correction factors with respect to sound pressure levels for audiometric zero at each frequency in each channel. During the first week of data collection, the audiometers used were Medical Dimensions Otomatic units. During the second week, one Beltone 9D audiometer and one Monitor MI 5000 unit were used. In all cases hearing thresholds were measured manually in 5-dB steps down to 0 dB hearing level using the Hughson–Westlake ascending–descending procedure. Biological calibration checks of audiometer function were carried out before each day of use.

The rooms used for audiometric testing were one small-group practice room and one office. The background sound pressure levels were monitored using a Rion NA61 precision sound level meter with a type NX-01A octave band filter unit. Sound levels in the practice room were within allowed specifications re: ANSI S3.1-1977 at 1 kHz and higher, but exceeded these levels by less than 10 dB at 0.5 kHz. Levels in the office exceeded the allowed specifications by 14 dB at 0.5 kHz and 5 dB at 1 kHz. However, the ER-3A insert earphones provide over 32 dB of mean attenuation of ambient sound at each octave band from 125–8000 Hz (Berger and Killion, 1989), thereby reducing the effective levels at the ear to within ANSI S3.1-1977 specifications. As an indication that background levels were acceptable for testing to audiometric zero, the subjects used for biological calibration checks could detect tones at 0 dB hearing level at all test frequencies from 0.5 to 8 kHz in both testing rooms, as could many of the study subjects.

Widely accepted practices for sound surveys and individual exposure monitoring were followed (Royster *et al.* 1986). Larson Davis 700 integrating sound level meter/dosimeters were used to measure the musicians' L_{eq} values (3-dB exchange rate). The computer capability of these instruments allows a complete time history of sound levels during the measurement period to be recorded and statistically analyzed. The dosimeter was supported around the musician's waist by a belt and was worn on the side or back of the hip. The microphone of each dosimeter was clipped onto the musician's collar. When the musician indicated that one ear would receive more noise exposure than the other, the microphone was placed on the side expected to receive the greater exposure. However, in the case of violinists and violists, it was necessary to place the microphone on the left side of the back of the collar in order not to interfere with the left-shoulder playing position of the instrument. For some violinists or violists who preferred that the microphone be kept away from the left side, it was placed on the right front collar instead. In these cases, an attempt was made to place the microphone well toward the front of the right collar in order to minimize the shadowing of the microphone by the musician's head and body.

Two musicians participated in exploratory testing of the difference in level between a microphone position near the left ear versus near the right ear of a violinist or violist. The measured difference was 6–8 dB(A) with the musician holding his head close to erect. If the player leans his left ear into the violin or viola more strongly, a greater exposure difference between ears occurs.

IV. RESULTS

A. Sound exposure measurements

Summary statistics for the measurement-period L_{eq} values are presented in the first column of Table I, and a frequency histogram of the L_{eq} distribution is shown as Fig. 1. The sample durations were usually 2 to 3 hs. The 41 readings made during the first week of data collection ranged from 79–99 dB(A) [mean = 89.3 dB(A)], and the 27 readings made during the second week ranged from 83–97 dB(A) [mean = 90.5 dB(A)]. Although the means and the maximum values for the two data collection periods are very close, the lower limit for the earlier period is 4 dB less than for the later period, probably due to the particular works of music being played and rehearsed. During the first period the program included one strings-only work, Haydn's Symphony No. 85, "La Reine," plus two full-orchestra works, Britten's Simple Symphony and Shostakovich's Symphony No. 5, Opus 47. During the second period the program consisted of Ran's Concerto for Orchestra and Berlioz' Symphonie Fantastique (Opus 14). As a few of the dosimetry readings from the first data collection period were from rehearsals which included only the string sections of the orchestra, the lowest L_{eq} values were obtained during these samples.

Some orchestra members expressed concern that even though overall L_{eq} exposures might not be excessive, the presence of very high sound pressure levels for brief periods of time might still harm their hearing. Whereas OSHA sets a limit of 140 dB peak sound pressure level for exposure to impact or impulse noises, there is very little evidence to support this limit according to Ward (1986). The safe peak sound pressure level increases as the duration of the impulse or impact decreases. Summary statistics for the maximum A-weighted peak SPLs recorded during dosimetry are shown in the second column of Table I. In 82% of the samples the maximum peak level was 130 dB(A) or below, and only two samples (3%) included peaks exceeding 140

TABLE I. Summary statistics for sound exposure measurements, dB(A).

	L_{eq}	Peak	Max. rms	8-h L_{eq}
Mean	89.8	124.9	106.4	85.5
s.d.	4.7	6.4	5.0	4.7
Median	90.0	124.0	106.8	85.7
Minimum	79.0	112.0	95.5	74.7
Maximum	99.0	143.5	115.5	94.7

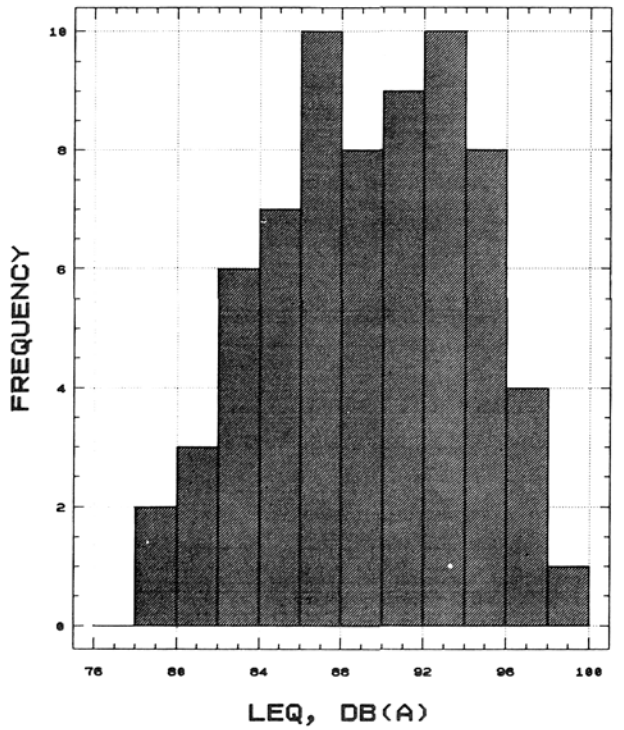

FIG. 1. Frequency histogram of L_{eq} values measured for dosimetry sampling periods.

dB(A). It is possible that these highest peaks may have occurred when the dosimeter microphone was accidentally bumped. The great majority of peak SPLs were in the range from 115–129 dB(A). (Note that although A-weighted peak values were reported, the values would be expected to increase only 1–2 dB if unweighted measurements had been made.) If these peak levels are representative, the chance of acoustic trauma occurring during orchestral music is quite small.

Perhaps a more meaningful indicator of the sound intensity during very loud musical passages is the maximum rms sound level measured during the dosimetry sample. Summary statistics for the maximum rms values recorded are shown in the third column of Table I. The maximum rms equivalent sound levels were 110 dB(A) or below for 76% of the samples, and the very highest value recorded was 115.5 dB(A).

B. Exposures for different instrument sections

To assess whether sound exposures differed for various instrument groups, the measured L_{eq} values were separated into the following groups:
group 1: violin and viola (23 samples);
group 2: horn, trumpet and trombone (13 samples);
group 3: clarinet, flute, bassoon, and percussion (17 samples);
and
group 4: bass, cello, harp, and piano (15 samples).

The resulting measured L_{eq} distributions for each group are presented as Fig. 2. Note that the L_{eq} values for the brass and percussion (group 2) and for those instruments situated in front of them (group 3) tend to be in the upper portion of the overall range of 79 to 99 dB(A). The L_{eq} values for violins and violas (group 1) are spread throughout the entire range, while values for group 4 fall in the lower half of the range.

C. Daily equivalent 8-h exposures

The L_{eq} values obtained for sampling periods had to be converted to equivalent daily 8-h exposures in order to use the ISO 1999 (1990) model to evaluate the potential NIPTS from orchestral music. The maximum on-the-job rehearsal and performance time for the Chicago Symphony Orchestra musicians is 15 hours per week. Therefore, each measured L_{eq} value was converted to a daily equivalent exposure by assuming that the measured value was repeated 15 hours per 40-h work-week. The resulting effect is to reduce each measured L_{eq} value by 4.3 dB; summary statistics for the equivalent daily 8-h L_{eq}'s are shown as the fourth column of Table I.

D. Hearing threshold levels

Presented as Table II are the mean binaurally averaged HTLs and standard deviations for all subjects and for various subgroups, as well as the number of subjects per group and their mean age.

E. Hearing thresholds by gender group

As expected, female musicians show better average HTLs than males especially at 3–8 Hz. However, both males and females show good average HTLs for their group mean age. In Fig. 3 the mean HTLs for male and female musicians are plotted together with the expected HTLs for two age-matched and sex-matched reference populations: the screened ISO 7029 (1984) reference data representing presbycusis alone, and the unscreened nonindustrial noise-exposed population (NINEP) assumed to represent typical hearing for citizens of the U.S.A. without industrial noise exposure but including the influences of other hearing hazards such as military service and other non-occupational noise exposure, plus medical pathology (Royster and Thomas, 1979). The musicians as a group show better average hearing than the unscreened NINEP, and their hearing is only slightly poorer than that of subjects screened to eliminate effects from any hearing hazard except aging.

F. Audiogram patterns

The data plotted in Fig. 3 suggest that there is a contribution from NIPTS in the HTLs of the musicians, as evident from the shape of their average audiograms, with relatively greater hearing loss at 2–4 kHz than at 6–8 kHz. All audiograms were examined to tabulate the percentage of ears showing patterns of hearing loss which are classically associated with NIPTS: (a) a dip or notch pattern with HTLs at 3, 4, and/or 6 kHz being 10 dB or more worse than adjacent lower and higher frequencies, or (b) a dip or notch of 10 dB or more superimposed on a sloping high-frequency-emphasis loss. Of the total of 118 ears, 53 (44.9%) showed a dip

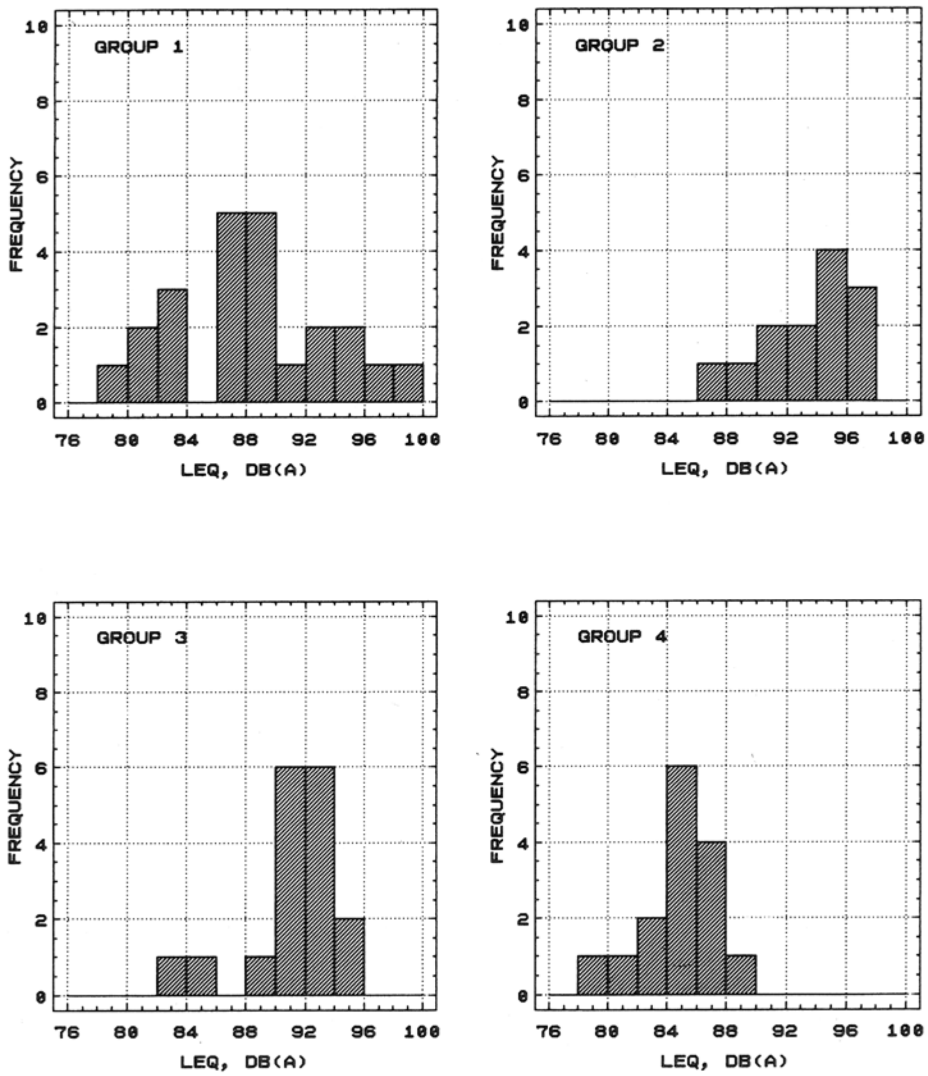

FIG. 2. Frequency histograms of sampling-period L_{eq} values measured for four instrument groups.

and 9 (7.6%) showed a dip superimposed on a sloping loss, for a total of 52.5% ears showing signs of NIPTS. In terms of individual musicians rather than ears, 42 persons (71%) showed audiometric patterns consistent with NIPTS in one or both ears.

G. Hearing thresholds by age group

Shown in Fig. 4 are the mean binaurally averaged HTLs for musicians in four age brackets (30–39 years, 40–49 years, 50–59 years, and 60–69 years) in comparison to the screened ISO 7029 (1984) and unscreened NINEP reference data for the matching age and the matching proportion of males and females. [The two musicians under age 30 were dropped from this analysis.] In general each age group's mean HTLs fall between the two reference populations, with slight to mild notched shapes which are consistent with the presence of some noise-induced hearing loss. The notched shape is most pronounced for the 40–49-year-old age group. However, even in this case the musicians' mean HTLs are about the same as the unscreened NINEP mean HTLs at 3–4 kHz in spite of the suggestion of some apparent NIPTS, and musicians' HTLs are similar to or better than the presbycusis median HTLs at 6–8 kHz.

H. Hearing thresholds by instrument group

As shown in Fig. 5, the mean HTLs for instrument groups appear grossly similar to each other, although the mean ages of the groups differ by up to about 8 yr. In order to evaluate HTL differences while accounting for age, the HTLs of each musician were age-corrected by subtracting the median values from the ISO 7029 (1984) presbycusis data for the matching age and sex. The mean binaurally averaged age-corrected HTLs of musicians by instrument group are presented as Table III, along with the total group and the same other subgroups for which data without age corrections were shown in Table II. The age-corrected results by instrument group are plotted as Fig. 6. Mean HTLs are similar for the instrument groups at 0.5, 1, 2, and 8 kHz, but group 4 (playing the quieter instruments—bass, cello, piano, and harp) shows the best hearing at the more noise-susceptible frequencies of 3, 4, and 6 kHz. Results for group 1 (violin and viola) fall about halfway between those for group 4 and those for groups 2 and 3.

To examine the possibility that interaural differences for violinists and violists might be obscured by averaging the HTLs of the two ears, the age-corrected HTLs of each ear

TABLE II. Mean binaurally averaged HTLs for musicians and standard deviations, dB.

Group	N	Mean age, years	Statistic	Hearing threshold level, dB Audiometric test frequency, kHz 0.5	1	2	3	4	6	8
Total	59	52.4	mean	11.0	8.6	13.9	21.0	25.8	24.7	24.4
			s.d.	9.3	9.2	11.4	15.1	18.2	16.6	20.1
Males	46	53.2	mean	12.1	9.5	14.3	23.2	29.0	27.1	25.5
			s.d.	9.8	10.0	11.1	15.4	18.6	17.2	20.8
Females	13	49.5	mean	7.1	5.6	12.5	13.5	14.6	16.0	20.4
			s.d.	6.1	4.5	12.6	11.5	11.9	11.0	17.9
Ages 30–39	12	35.3	mean	7.7	6.7	8.1	9.8	12.3	12.9	11.8
			s.d.	6.1	6.1	7.5	8.5	10.1	9.5	13.6
Ages 40–49	12	46.3	mean	6.3	3.5	9.2	23.1	24.2	17.7	8.5
			s.d.	4.5	3.6	7.0	19.4	18.9	12.8	9.2
Ages 50–59	13	55.1	mean	13.5	10.0	16.4	21.4	24.0	25.6	26.2
			s.d.	12.5	8.0	13.3	13.3	12.9	13.2	12.3
Ages 60–69	14	64.6	mean	12.3	12.3	19.6	28.8	42.1	39.1	40.2
			s.d.	8.2	10.6	11.0	13.6	17.8	17.1	20.3
Ages 70 and up	6	72.8	mean	19.2	12.5	18.8	25.0	29.2	33.3	46.7
			s.d.	12.1	16.7	15.2	13.3	14.7	12.9	15.9
Group 1: violin and viola	27	54.9	mean	11.0	10.1	15.3	22.4	27.7	26.4	25.9
			s.d.	9.2	11.2	12.1	15.0	16.7	16.0	20.5
Group 2: horn and trumpet	7	46.7	mean	7.5	5.0	10.4	17.9	21.8	21.8	17.1
			s.d.	7.1	6.1	8.1	14.5	16.9	13.8	16.2
Group 3: clarinet, flute, bassoon, percussion	12	48.3	mean	11.5	7.7	11.7	22.9	26.5	25.0	21.7
			s.d.	12.7	8.0	13.5	18.7	22.1	19.7	17.7
Group 4: bass, cello, piano, harp	13	53.9	mean	11.0	6.5	12.9	15.0	20.2	19.2	24.2
			s.d.	6.9	4.5	7.7	10.3	17.4	15.3	22.5

were plotted by instrument group, as shown in Fig. 7. Although the left ears of group 1 show similar HTLs to group 2 and 3, their right ears are similar to those of group 4.

A least-squares analysis of variance was performed on HTL as a function of instrument group, ear, and frequency category (the noise-susceptible frequencies 3, 4, and 6 kHz versus 0.5, 1, 2, and 8 kHz. The least-squares adjusted means (adjusted for the unequal group sizes) at 3, 4, and 6 kHz in the left ear were significantly better for group 4 than for the other groups, which were equivalent. In the right ear, groups 1 and 4 both show significantly better mean HTLs than groups 2 and 3.

I. Hearing thresholds by left and right ear

The results indicating poorer hearing in the left ear than in the right for group 1 can probably be attributed to a difference in sound exposure between ears. The left ear of a violinist or violist receives greater exposure than the right because it faces the sounding board and (for some players) is tilted very close to the instrument, while the right ear is somewhat

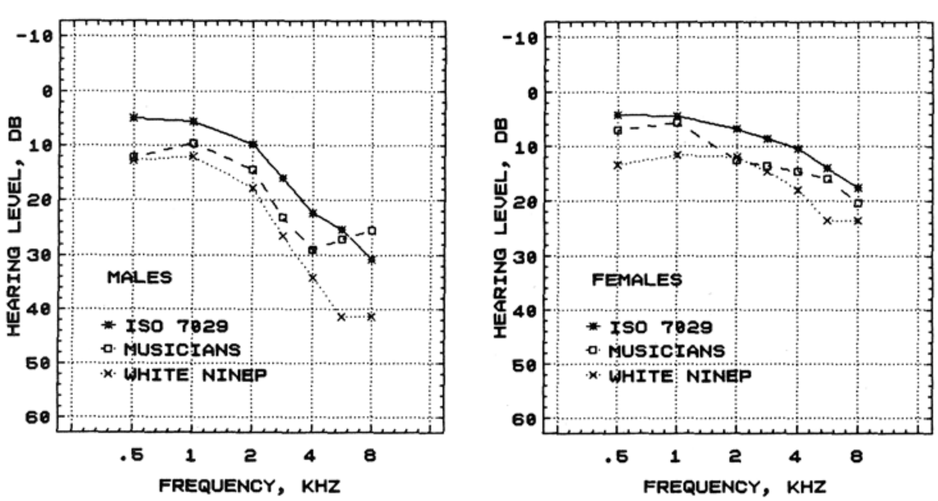

FIG. 3. Mean hearing thresholds of male and female musicians compared to data from two reference populations matched by sex and age: the screened ISO 7029 (1984) presbycusis population, and the unscreened white nonindustrial noise-exposed population (NINEP).

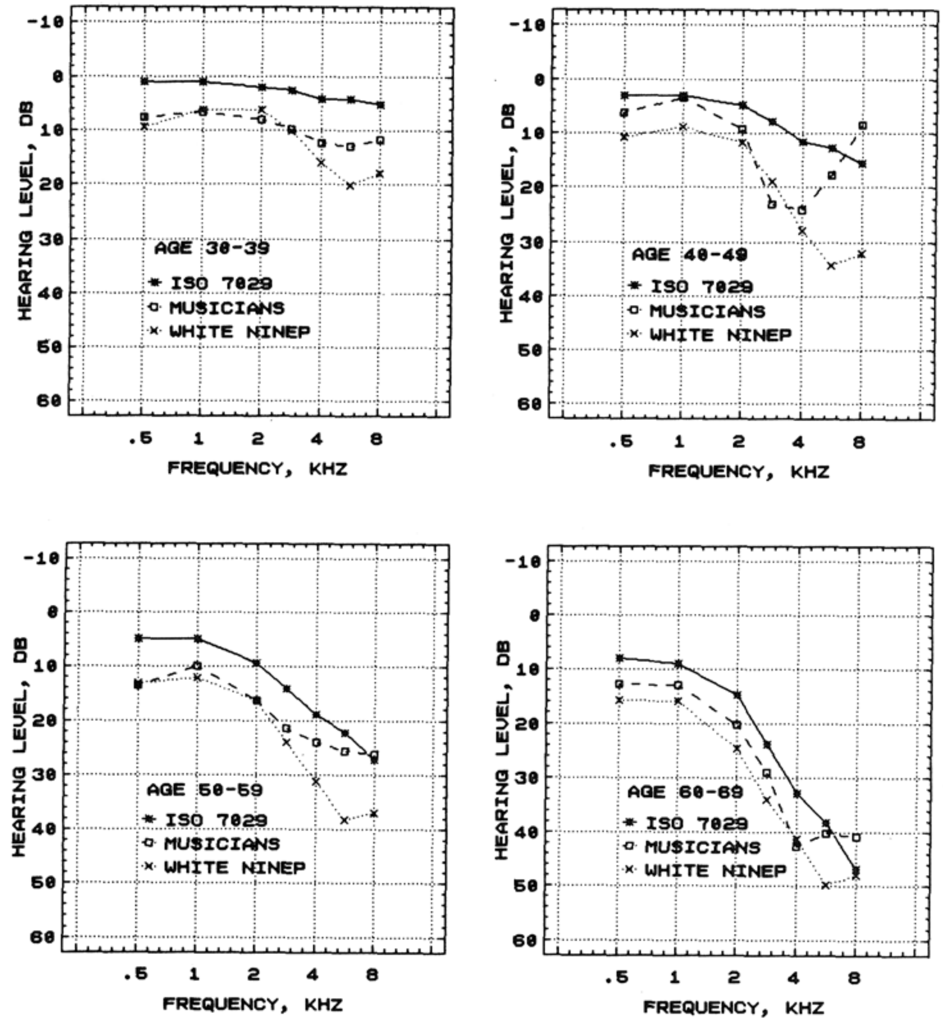

FIG. 4. Mean hearing thresholds of musicians in four age ranges compared to data from two reference populations matched by sex and age: the screened ISO 7029 (1984) presbycusis population, and the unscreened white nonindustrial noise-exposed population (NINEP).

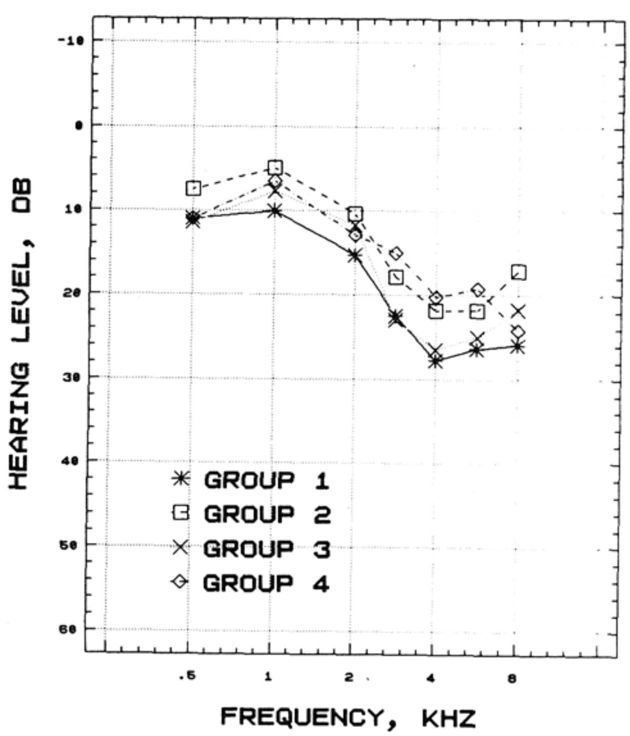

FIG. 5. Mean hearing thresholds of musicians in four instrument groups.

protected by a head shadowing effect and greater distance. (As noted in the instrumentation section, an exposure difference of 6–8 dB(A) between ears was documented.)

The differences in HTLs between the two ears for individuals in the four instrument groups were analyzed in paired-comparison t tests to determine whether musicians in any instrument group exhibited mean ear differences which were significantly different from zero. For violinists and violists, the left-minus-right ear difference of 5.74 dB at 4 kHz was significantly different from zero ($t = 2.04, p < 0.05$) and the difference of 4.44 dB at 3 kHz approached significance.

Because interaural differences did not approach significance for any instrument group except group 1, groups 2–4 were combined for a new analysis. The average left-minus-right ear differences for violinists and violists versus all other musicians are presented in Fig. 8. Positive difference values indicate worse hearing in the left ear, and negative values indicate worse hearing in the right ear. The average interaural differences are all smaller than 2 dB except for group 1 (violinists and violists) at 2, 3, 4, and 6 kHz, where average differences of about 3–6 dB are found.

A least squares analysis of variance was performed on interaural difference in HTL as a function of frequency category (0.5, 1, 2, and 8 kHz versus the noise-susceptible 3, 4, and 6 kHz), and instrument category (violinists and violists

TABLE III. Mean binaurally averaged HTLs for musicians and standard deviations, dB, corrected for age by subtraction of median ISO 7029 presbycusis data.

Group	N	Mean age, years	Statistic	Hearing threshold level, dB Audiometric test frequency, kHz 0.5	1	2	3	4	6	8
Total	59	52.4	mean	6.0	2.8	4.2	5.9	5.3	1.2	− 4.4
			s.d.	8.7	8.2	10.0	14.0	15.7	13.2	14.4
Males	46	53.2	mean	5.9	2.8	4.2	5.8	5.3	1.1	− 4.7
			s.d.	8.7	8.3	10.1	14.2	15.8	13.3	14.4
Females	13	49.5	mean	3.0	0.9	5.5	4.7	4.1	1.9	2.8
			s.d.	4.8	4.2	10.8	9.5	10.3	9.0	9.0
Ages 30–39	12	35.3	mean	5.4	3.6	3.8	4.0	5.3	5.2	2.0
			s.d.	6.8	3.6	4.5	5.2	5.7	4.2	4.9
Ages 40–49	12	46.3	mean	3.4	0.3	3.6	14.2	11.8	3.7	− 8.7
			s.d.	4.3	3.6	6.6	18.2	17.7	11.9	8.6
Ages 50–59	13	55.1	mean	8.6	4.5	7.1	7.1	4.9	3.2	− 1.3
			s.d.	11.9	7.5	12.8	12.2	11.2	11.7	11.2
Ages 60–69	14	64.6	mean	4.7	3.6	4.7	5.0	9.6	1.8	− 5.5
			s.d.	7.8	10.2	10.8	13.6	17.6	15.6	18.2
Ages 70 and up	6	72.8	mean	8.6	0.4	− 1.9	− 7.8	− 15.8	− 18.1	− 16.4
			s.d.	10.8	14.8	13.1	11.7	12.5	10.3	21.9
Group 1: violin and viola	27	54.9	mean	5.6	3.9	4.7	5.8	5.0	0.3	− 6.1
			s.d.	7.7	9.6	10.1	14.8	15.7	14.2	17.4
Group 2: horn and trumpet	7	46.7	mean	4.4	1.5	4.2	7.8	7.9	6.1	− 2.1
			s.d.	5.7	5.0	6.0	11.0	13.9	7.7	9.1
Group 3: clarinet, flute, bassoon, percussion	12	48.3	mean	7.6	3.2	3.9	10.1	8.8	5.0	− 2.7
			s.d.	12.6	8.2	12.7	16.7	18.6	15.1	12.8
Group 4: bass, cello, piano, harp	13	53.9	mean	6.0	0.6	3.3	0.4	0.7	− 3.8	− 4.1
			s.d.	6.3	5.4	7.9	7.5	11.3	8.2	9.9

versus all other musicians). Comparisons among adjusted least squares means indicated that the left-minus-right ear differences for violinists and violists both at 0.5–2 and 8 kHz and at 3–6 kHz were significantly greater than the differences for other musicians.

J. Hearing thresholds as a function of L_{eq}

There were 32 musicians for whom both audiograms and dosimetry estimates of L_{eq} were obtained. Using the age-corrected data to account for the influences of age and sex, a series of linear regressions was performed on HTL at each frequency in each ear as a function of L_{eq}. The L_{eq} measured for the individual musician did not predict HTL at 0.5 to 2 kHz, but F ratios did reach significance at 3 to 6 kHz in the left ear and at 3 to 8 kHz in the right ear, as shown in Table IV. These findings are consistent with the ISO 1999 (1990) model, which predicts no appreciable NIPTS at the lower audiometric test frequencies for the low L_{eq}'s measured for the musicians studied. However, L_{eq} accounted for only 10% to 27% of the variance in HTLs at the higher frequencies.

V. DISCUSSION

A. Predicted hearing damage

The ISO 1999 (1990) model was used to estimate the amount of NIPTS which would be expected to occur over many years from the typical musicians' on-the-job sound exposure. Assuming the median on-the-job exposure [8-h daily $L_{eq} = 86$ dB(A)] for ears of average susceptibility (the 0.5 fractile), the model predicts that 6–8 dB of NIPTS at 3–4 kHz would be expected after 30 years of exposure at this level. Of course, ears of low susceptibility would develop less NIPTS than this. For the same exposure, ears of very high susceptibility (the 0.05 fractile) would develop about 10 dB of NIPTS at 3–4 kHz over 30 yr.

If a noise exposure from the upper portion of the range for musicians is used instead of the median exposure, a greater amount of NIPTS is predicted. An 8-h daily L_{eq} of 92 dB(A) represents the 90th percentile of the distribution of on-the-job L_{eq}'s estimated for musicians (that is, only 10% of measured values were higher than this). Using this more extreme exposure, average-susceptibility (0.50 fractile) ears would be expected to develop up to 18 dB of NIPTS, and very susceptible ears (0.05 fractile) would be expected to develop up to 26 dB of NIPTS.

B. Implications for individual musicians

The findings of this study predict a small amount of NIPTS for a population of musicians of average susceptibility to noise damage based on 15 h per week of on-the-job noise exposure at the typical levels recorded during rehearsals and performances. However, individuals with higher

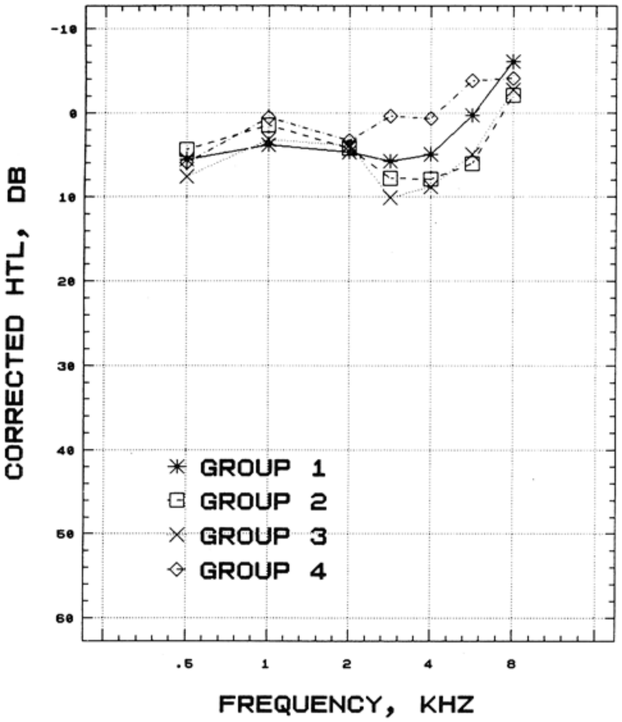

FIG. 6. Mean age-corrected thresholds of musicians in four instrument groups.

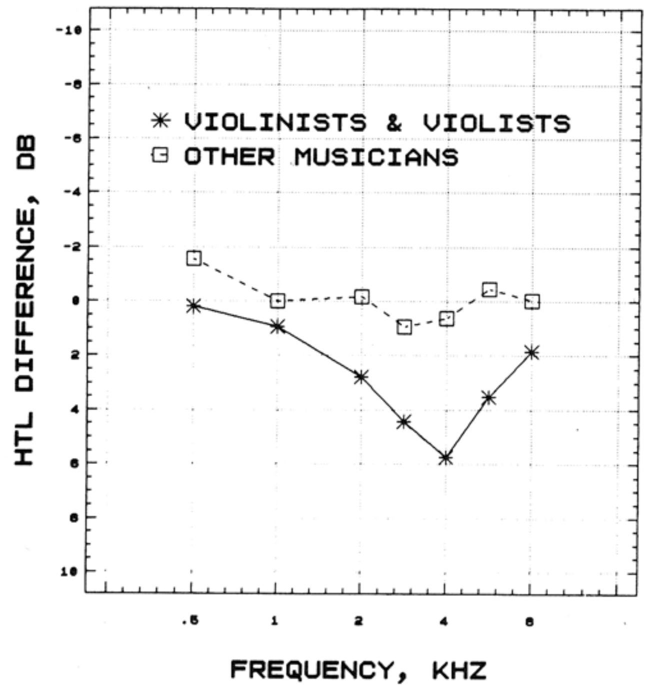

FIG. 8. Mean interaural threshold difference (left ear HTL minus right ear HTL) for violinists and violists and for other musicians.

susceptibility to noise-induced hearing loss could develop substantial NIPTS if their noise exposures were in the upper end of the range of equivalent daily 8-h L_{eq}'s measured during this study for on-the-job exposures of 15 h per week.

Musicians who have significant off-the-job noise exposures would be at greater risk of developing hearing loss than indicated in this study for on-the-job exposures. Most musicians practice long hours, but the exposure during practice time depends on the instrument played. Some instruments create an exposure for the player during solitary practice which is potentially as damaging as an orchestral performance. In fact, practice exposures for some musicians may be higher than performance exposures since they may play more continuously and/or may selectively repeat the more difficult louder passages. For musicians playing such instruments, the total risk of hearing damage is certainly higher than the on-the-job risk even if they do not play in any musical groups other than the orchestra, but simply practice alone.

Although this study did not investigate in detail the sound levels of isolated instruments at the player's ear, special dosimetry on two individuals playing violin and viola yielded sound exposures equal to full-orchestra values. Dosimetry results for the co-concert-master, practicing violin alone on four separate occasions, yielded L_{eq} values of 93.3, 95.1, 95.4, and 96.6 dB(A), each for a period of from 1.5 to 5.7 h. It is expected that solitary practice with brass instruments also would create significant exposures for the players.

In contrast, other instruments are not significant sound sources for the player. For musicians who play the quieter instruments, solitary practice contributes very little to total exposure, and the risk of hearing damage would come from the on-the-job exposures alone (unless they also play in other groups which create potentially hazardous sound levels).

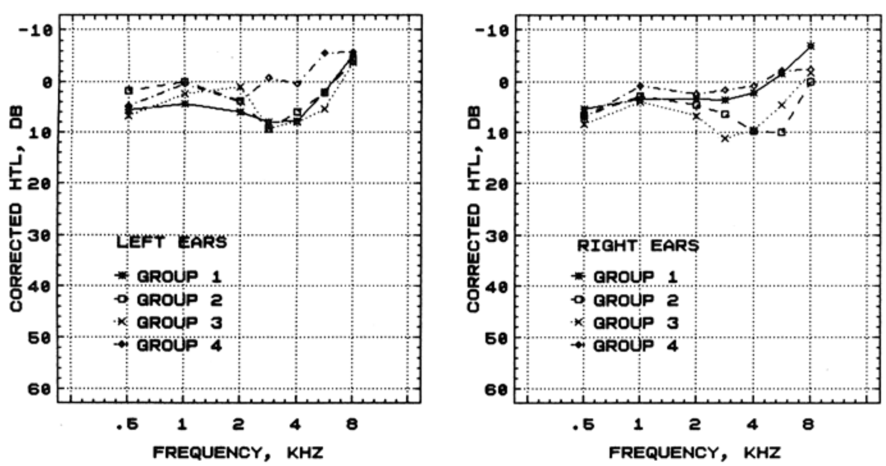

FIG. 7. Mean age-corrected thresholds for left versus right ears of musicians in four instrument groups.

TABLE IV. Results of regression analyses on age-corrected HTLs as a function of L_{eq}.

Ear	Frequency in Hz	F	Probability of greater F	r squared
Left	500	2.50	0.1245	0.0769
	1000	0.93	0.3415	0.0302
	2000	1.02	0.3206	0.0329
	3000	11.12	0.0023	0.2705
	4000	7.06	0.0125	0.1905
	6000	3.15	0.0858	0.0952
	8000	0.32	0.5769	0.0105
Right	500	1.81	0.1892	0.0568
	1000	1.60	0.2153	0.0507
	2000	0.00	0.9810	0.0000
	3000	7.72	0.0093	0.2046
	4000	5.74	0.0230	0.1607
	6000	8.96	0.0055	0.2300
	8000	8.91	0.0056	0.2289

Therefore, the upper limit of the distribution of total L_{eq} values from both on-the-job and off-the-job playing time would be expected to be much higher than the range of only on-the-job exposures measured in this study. If total L_{eq} were known, it should account for more of the variance in HTLs than did on-the-job L_{eq}.

For musicians, any unnecessary hearing loss is undesirable. Furthermore, NIPTS may be preceded or accompanied by other auditory symptoms such as tinnitus, reduced frequency resolution, or reduced temporal resolution; these symptoms may also create difficulty in musical perception. Since it is impossible to predict which individuals are highly susceptible to NIPTS, regular audiometric monitoring is needed to detect any beginning changes so that affected individuals can take protective actions. Wearing hearing protectors during practice as well as rehearsal and/or performance would reduce total sound exposure for musicians whose own instruments are a significant sound source. For players of quieter instruments, hearing protectors would reduce total exposure if worn only during rehearsal and/or performance. Recently developed earplugs with attenuation which is flat across frequency should be more acceptable to musicians than conventional devices which provide greater attenuation of the higher frequencies (Killion *et al.*, 1988).

VI. NEEDS FOR FURTHER STUDY

The results of this investigation point out areas in which additional information is needed.

(1) To define the total sound exposure of musicians, off-the-job noise exposures for representative musicians should be monitored through personal dosimetry as they participate in their normal practicing, teaching lessons, and/or playing in other musical groups.

(2) To determine the contribution of the sound from the instrument being played to the overall exposure, data should be collected during solitary practice and orchestral rehearsal and performance of the same musical works for musicians playing each instrument, including measurement of both the left and right ear exposures for violinists and violists.

ACKNOWLEDGMENTS

The authors express their sincere gratitude to the members of the Chicago Symphony Orchestra who participated in this study. In particular, we appreciate the invaluable assistance of Vanessa Moss, Deborah Oberschelp, Julie Griffin, and Andrea Friederici for their assistance in the arrangements for this study and its execution. Amoco Corporation generously loaned five dosimeters to the Chicago Symphony Orchestra for this study, thus allowing the collection of a greater number of sound exposure samples than would otherwise have been possible. The authors especially thank Janice Florin, the Manager of Environmental Affairs and Safety at Amoco, for making this loan.

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