A Proposition 65 Risk Evaluation of Lead in @@ Guitar Strings

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1. Overview and Introduction

A recent notice[1] alleges that use of @@ musical guitar string products poses a significant risk of birth defects and other reproductive harm and cancer. In particular, it is implied that the presence in these products of lead and/or lead compounds would result in a dose to an average consumer and/or occupational user larger than California's Maximum Allowable Daily Level (MADL) for reproductive toxicity and/or No Significant Risk Level (NSRL) for cancer.

On its face, this claim is not credible, and cannot have been supported by any reliable data and exposure assessment. Standard wipe-test data (presented below) indicate only infinitesimal quantities of lead available on the surface of these strings, such that an average guitar player would have to lick over the entire length of such a string about 9–12 times per day, or somehow obtain an equivalent dose, in order to ingest more than the maximum allowable dose. Further exposure assessment (presented below) demonstrates that even worst-case exposures to these guitar strings do not result in any significant dose of lead, and so do not result in the alleged violation.

Lead is present at low concentrations in @@ guitar strings because of the use of tin plating, bronze, and brass[2] to construct those strings. Lead contamination of these materials is practically inevitable, and its concentration is controlled at sufficiently low levels by the specifications provided by its suppliers of products (wire) containing tin, bronze, or brass.
As detailed below, the presence of lead in @@ guitar strings is of no toxicologic significance.

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[1] 60-Day Notice of Violation In Compliance with California Health & Safety Code §25249.7(d), from @@

[2] The bronze and brass are not "leaded" — no lead is deliberately added; see Section 3.1.

2. Proposition 65 "No Significant Risk" dose and "Maximum Allowable Dose Level"

The Reproductive and Cancer Hazard Assessment Branch of OEHHA is the lead agency for the implementation of the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65), and in that role has established no significant risk levels (NSRLs) for carcinogens and maximum allowable dose levels (MADLs) for chemicals causing reproductive toxicity. The latest available list of these levels is dated February 2009 (OEHHA, June 2009), and indicates an NSRL of 15 μg/day for lead, with higher values for several other lead compounds, and a MADL of 0.5 μg/day for lead.

In assessing NSRLs for carcinogens, the relevant time frame for exposure is the long-term average, where long term is typically taken to be a 70-year lifetime.[3] In assessing MADLs for chemicals causing reproductive toxicity, the relevant time frame for exposure is a 9-month average.[4] In what follows, we show that even when exposures are averaged over only a single day, the MADL for lead is not exceeded.

3. Concentration of lead in @@ guitar strings

3.1. Raw material specifications and measurements

The @@ guitar strings cited in the Proposition 65 notice (Footnote 1) are constructed in various ways. "Plain" strings have a steel core wire that is tin plated (about 0.3 mils thickness of tin, or 0.0003 inches), with no further treatment. Coated plain strings have a steel core that is zinc coated, with a subsequent polymer coating. The strings for lower notes (with higher gauges) have a tin-plated steel core wire wrapped with wire made from phosphor-bronze (ASTM B 159/B 159M, UNS# C51000, 95:5 copper:tin), brass (ASTM B 134/B 134M, UNS# 24000, 80:20 copper:zinc), or nickel-plated steel. For some of the wrapped strings, the bronze or brass is polymer coated.

ASTM B 134/B 134M, UNS# 24000 for brass specifies a lead content <0.05% (<500 ppm); ASTM B 159/B 159M, UNS# 51000 for phosphor-bronze specifies a lead content of <0.05% (<500 ppm). The nickel-plated steel wire is certified as using nickel with a lead content that is below detection limits. The lead content of a tin ingot used for tin plating has been measured at 188 ppm; similar values would be expected for other lots of tin used for this purpose, and the lead content is here assumed to be 200 ppm. A test of a 16 mil (0.016 inch) diameter tin-plated steel core wire measured an undetectable lead content (<0.001%, or <10 ppm), but that would be expected unless the lead content of the tin exceeded about 260 ppm; the test shows, however, that the core steel itself contains less than 10 ppm lead. The manufacturer of the polymer materials claims to use no lead compounds in their formulation, and provided a test of wire samples coated with the polymer that showed non-detect (<3 ppm lead).

3.2. Wipe test results

Based on the raw material specifications, the maximum potential exposures to lead from @@ guitar strings would occur from those strings that are tin plated, or those wrapped with brass or

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[3] See Title 27, Division 4, Chapter 1, §25721, California Code of Regulations.
[4] See Title 27, Division 4, Chapter 1, §25821, California Code of Regulations.

phosphor-bronze. Accordingly, wipe tests were conducted of a tin-plated string, a brass wrapped string, and a phosphor-bronze wrapped string, each of the heaviest gauge used (ensuring the largest surface area exposed to the wipe testing) and polymer-free.

The wipe tests were conducted by Bodycote Testing Group (Job number 115047) according to the method of NIOSH 9100 (slightly adapted to testing strings rather than flat surfaces) using Bodycote's proprietary standard operating procedure 7040, Rev 10, including the use of ICP-MS for measurement of lead. The adaptation of NIOSH 9100 (which calls for wiping of a 10 × 10 cm area "or other standard size") involved[5] wiping the whole length of string — so the whole length of the string was pulled through the pre-moistened wipe, the wipe was folded and the pull through repeated, and the wipe was then folded again and the pull through repeated.

The results obtained from Bodycote Testing Group were (at a detection limit of 0.01 μg):

Blank Wipe (Ghost wipe)	0.10 μg
Tin-plated plain string	0.24 μg
Phosphor-bronze wrapped string	0.13 μg
Brass wrapped string	0.17 μg

The heaviest gauge strings supplied by @@ were used in these tests, to ensure the maximum surface areas. Bodycote also supplied data on 10 recent blank wipes (9/10/08 through 6/1/09), the average amount of lead in the blanks being 0.10 μg with standard deviation 0.0125 μg, max 0.12 μg, min 0.08 μg.

Subtracting the blank wipe value, the observed amounts of lead wiped from the full length of the strings supplied was 0.14 μg for the tin-plated steel plain string, 0.03 μg for the phosphor-bronze wrapped string, and 0.07 μg for the brass-wrapped string.

4. Initial screening evaluation

The wipe data presented in Section 3.2 confirm the trace nature of any lead present in the construction materials of the strings, and indicate that the worst-case potential exposure to lead might occur with tin-plated strings. The quantity of lead detected from the tin-plated string amounts to about 0.14 μg per wiped string with 3 wipes. To obtain an exposure of 0.5 μg/day would require that a user lick over the whole length of such a string about 9–12 times per day, or somehow obtain an equivalent exposure (assuming that the wipe did not just remove easily available surface material, or that such material refreshes within less than a day, and that any the surface contamination of the string detected by these wipe tests actually arises from the material of the string and not from incidental environmental contamination). For brass-wrapped strings and phosphor-bronze strings, the quantities of lead detected were 0.07 μg and 0.03 μg respectively, which would require licking the whole length of string about 21 times per day and 50 times per day respectively to ingest 0.5 μg of lead per day. Such behavior is certainly not that of an average user (whether amateur or professional musician), and an equivalent behavior is

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[5] Private telephone conversation with Samina Hussain, Metals Group Leader, 526-948-2225 x502, on June 3, 2009.

difficult to imagine. Nonetheless, in what follows, we utilize published measurements of transfer of metals from coins to people's fingers; so doing, we demonstrate that the MADL for lead is not exceeded under even worst-case conditions.

5. Detailed evaluation of exposure pathways

Average users' most extensive exposure to @@ guitar strings will result from the intended use of these strings on musical instruments; that is, amateur or professional musicians playing guitars or equivalent instruments. Such musicians are certainly exposed to at least some quantity of metals from instrument strings, as is evident from literature reports of nickel allergies resulting from use of nickel-plated strings (Smith *et al*. 2006).

During this use, musicians will contact the strings with the fingers of both hands (for a right-handed player using a pick, the contact will be relatively small on the right hand). In the process, the musician's fingers will rub metal from the surface of the strings (if they are bare metal — polymer covered strings will prevent all exposure to metals while the polymer remains intact), and some of that metal may stick to the surface of the fingers. Subsequently, some metal may be absorbed transdermally, and some may be ingested if there is hand-to-mouth contact.

5.1. Amount of lead rubbed from guitar strings on to fingers

5.1.1. Experimental measurements of metal transfer

We have not located any studies of the amount of lead transferred to fingers through finger contact with any type of metal, or indeed any measurements of any metal present in only trace quantities in an alloy (as is lead in the tin, brass, and phosphor-bronze of interest here). However, there are studies of the transfer of metals from coins to fingers, primarily in evaluation of the extent of exposure to nickel from the copper/nickel/zinc/tin alloys used in coins. These studies give quantitative information that may be used to extrapolate the potential amount of lead transferred from the trace quantities of lead present in the alloys used in the construction of @@ guitar strings.

Fournier and Govers (2003) demonstrated contamination of the finger of volunteers by nickel (Ni), copper (Cu), and zinc (Zn) during manipulation of French 2 franc and European 2 euro pieces taken straight from circulation ("unwashed"), after washing by 10 minutes immersion in demineralized water in an ultrasonic bath ("washed"), and after rubbing the coins to a shiny finish ("polished"). The 2 franc pieces had been in circulation for several years, and the 2 euro pieces for between 2 and 5 months. Each volunteer handled 58 coins (counting them by transferring them from one plastic container to another), with an average handling time of 2.6 sec per coin (range about 2 to 3 sec depending on the volunteer). Each volunteer used three fingers for such handling (thumb, index, and middle finger), and the metal content[6] of material transferred to these fingers was measured. The metal content of the material transferred to the 3 fingers, per coin, in each handling, is shown in Table 1.

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[6] The actual material transferred is probably a metal oxide, rather than pure metal (see Section 5.3).

Table 1 Total amount of metal content transferred to 3 fingers by handling, μg/coin handled, with 90% confidence limits (Fournier and Govers, 2003)

	French 2 franc coins			European 2 euro coins		
Metal	Unwashed	Washed	Polished	Unwashed	Washed	Polished
Ni	0.38 ± 0.10	0.46 ± 0.16	0.009 ± 0.004	0.23 ± 0.06	0.26 ± 0.07	0.012 ± 0.006
Cu	0.44 ± 0.10	0.24 ± 0.07	0.013 ± 0.004	1.4 ± 0.2	1.3 ± 0.2	0.10 ± 0.01
Zn	0.14 ± 0.03	0.12 ± 0.04	0.012 ± 0.003	0.26 ± 0.03	0.28 ± 0.05	0.07 ± 0.03

European 2 euro coins have a complex structure — a center disk that has a core of nickel with a surface of nickel brass (75% Cu, 20% Zn, 5% Ni), and an outer ring of copper-nickel (75% Cu, 25% Ni), so transfer of all three metals would be expected from the 2 euro coins. The results for French 2 franc coins are inexplicable in terms of the base materials of the coins, since they are pure nickel yet appreciable quantities (compared with nickel) of copper and zinc were transferred from such coins. The results are, however, explicable in terms of the metals removed from the surface of the coins during polishing (Table 2). Evidently, the surface of coins becomes contaminated by other metals (*e.g.* from other coins) during everyday circulation, and it is metal from this surface film that is transferred to fingers during handling.

Table 2 Average metal content (μg) in surface film removed from each coin during polishing.

Metal	2 franc coin	2 euro coin
Ni	12	5
Cu	13	38
Zn	2	8

Using the data in Table 1 and correcting (hypothetically) to a surface consisting of 100% of the selected metal using the measured fractional surface metal composition of Table 2, and using the 2.6 second handling time (for reasons explained below), gives the results of Table 3 for the initial rate of transfer of metal content to the 3 fingers involved during coin handling.

Table 3 Average transfer rate, μg/sec, to 3 fingers while handling coins, normalized to 100% surface availability of the given metal.

	2 franc coin			2 euro coin		
Metal	Unwashed	Washed	Polished	Unwashed	Washed	Polished
Ni	0.329	0.398	0.008	0.902	1.020	0.047
Cu	0.351	0.192	0.010	0.723	0.671	0.052
Zn	0.727	0.623	0.062	0.638	0.687	0.172

The results of Table 3 show relatively good consistency between the transfer rates for unpolished coins when evaluated this way, and indicate that the metal transferred is probably from a surface layer of material on the coins that may differ considerably from the base material of the coin. They also show that when the surface-removable material (probably an oxide layer, see Section 5.3) is depleted by polishing, the transfer rates generally decrease about 10-fold or more (although only about 4-fold for zinc on the 2 Euro coin). The results for the 2 Franc coin after polishing show that appreciable quantities of zinc and copper remained on the surface of that coin even after polishing.

The transfer rates shown in Table 3 for the unpolished coins cannot, however, continue for very long without depleting the removable material. Table 4 shows the handling time in seconds (at 2.9 sec per coin) required to remove the amount of material shown in Table 2 based on the measured transfer rates of Table 1.[7]

Table 4 Handling time (seconds) to remove the polishable material from coins

	2 franc coin		2 euro coin	
	Unwashed	Washed	Unwashed	Washed
Ni	82	68	57	50
Cu	77	141	71	76
Zn	37	43	80	74

Fournier and Govers (2003) also showed that there appeared to be a distinct surface layer of more readily removable material in leaching tests. A short-term test of 80 minutes leaching 2-euro coins in demineralized water showed linear leaching at a rate approximately 7 times higher than long-term tests, with the total amounts per coin of Ni, Cu, and Zn removed in the 80 minutes of leaching approximating those shown in Table 2 (approximately 28 μg Cu, 8 μg Ni, and 5 μg Zn). Even the short-term leaching rates were, however, much too low to account for the transfer of metals seen in Table 1, so the primary transfer mechanisms presumably involves friction rather than dissolution in sweat.

Gwozdz and Grass (2004) evaluated transfer of metals from metal foils and metallic objects to fingers by quantifying the transfer of metal to filters that were rubbed by fingers that had previously rubbed metal foils or metal objects. The contact here may have been more intense than that recorded by Fournier and Govers (2003), since the volunteers actively rubbed the metallic objects between fingers (and then the filter). However, no attempt was made to evaluate the fraction of material on the fingers that was rubbed on to the filters. The total time taken for both operations was about 30 seconds, so we assume here that the rubbing of metal materials took 15 sec. Assuming quantitative transfer of metal from fingers to filters, Table 5 shows the total transfer rate (to finger and thumb combined) in μg/sec during the metal rubbing for those cases where the measured metal was the same as the metal of the object rubbed, and the object was primarily composed of the measured metal.[8] It can be seen that the transfer rate is very

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[7] The implication is that a minute or two of rubbing a coin between the fingers will polish it fairly effectively; and this indeed works.

[8] Gwozdz and Grass (2004) also measured transfer of trace metals, but gave no information on the concentrations of those trace metals in or on the surface of the objects rubbed. Based on the observations

variable in these measurements, and that for pure soft metals it can reach the transfer rates shown in Table 3.

Table 5 Transfer rate from foils or 100% metal objects during rubbing by fingers, µg/sec

Metal	Object	Person A	Person B
Gold	Ring	0.013	0.008
	Watch	0.002	0.002
	Chain	0.001	0.036
Silver	Spoon	0.037	0.045
	Bracelet	0.025	0.043
	Necklace	0.167	0.080
Zinc	Foil	0.253	0.247
Cadmium	Foil	0.033	0.027
Tin	Plate	0.533	0.200
Cobalt	Foil	0.031	0.127
Nickel	Foil	0.160	<0.003

Subsequent measurements of metal transfer have generally been concerned with nickel, primarily because of nickel's propensity to cause allergic reactions. Staton *et al.* (2006) developed a quantitative methodology for extraction of metals on fingers by dipping the finger in ultrapure water for 2 minutes, which gave an extraction efficiency of 91% with one wash.[9] They showed that during deliberate rubbing between finger and thumb of pre-cleaned British 20 p coins (16% Ni, 84% Cu), the quantity of nickel transferred to finger and thumb increased linearly over a period extending at least up to 15 minutes. This observation of linearity with time justifies the presentation of results in Table 3, Table 5, and Table 6 as a transfer rate per unit time.[10]

Assuming that the surface metal concentrations were similar to the bulk metal, the transfer rates (normalized to 100% surface Ni concentration) observed by Staton *et al.* (2006) for two volunteers in this procedure were 0.044 µg/sec and 0.020 µg/sec,[11] approximately one tenth those obtained from unwashed and washed coins by Fournier and Govers (2003), see Table 3. These coins were "gently cleaned with high purity water and left to air dry." Such treatment, if it

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of Fournier and Govers (2003) discussed above, such measurements give no useful quantitative information on transfer rates, and do not contradict what is shown here either qualitatively or quantitatively.

[9] Table 3 shows that water immersion is not effective at removing the surface layers from metals.

[10] This would apply at least until the surface layers, measured for example in Table 2, are depleted.

[11] Staton *et al.* (2006) give the average concentrations (89.6 µg/liter and 40.9 µg/liter) in the 35 ml of ultrapure extraction water used for each of the finger and thumb. Thus 6.27 µg (=89.6 × 2 × 35/1000) and 2.86 µg (=40.9 × 2 × 35/1000) transferred respectively, corresponding to 6.27/(15 × 60 × 0.16) = 0.044 µg/sec and 2.86/(15 × 60 × 0.16) = 0.020 µg/sec)

involved any rubbing or an immersion exceeding a few tens of minutes, could have removed some fraction of the polishable material observed by Fournier and Govers (2003), so these rates may be comparable with the rates obtained for polished coins by Fournier and Govers (2003).

Staton *et al.* (2006) also evaluated the effect of handling pre-cleaned British 1 pound coins (5.5% Ni, 24.5% Zn, 70% Cu) for two minutes. Normalizing their results to 100% Ni, assuming that the surface Ni content of the coin corresponds to its bulk Ni content, gives the values shown in Table 6; however, while these range from about 1/10th to equality with the values in Table 3, they may be considerably in error because of the potential difference of the surface layer from the bulk metal.

Table 6 Transfer rates observed by Staton *et al.* (2006), normalized to 100% Ni using bulk material concentrations

Subject	Transfer rate, μg/sec, in four experiments with 2 minutes of rubbing			
	Using 1 pound coins (Ni content 5.5%)	Using 20 p coins (Ni content 16%)		
A	0.263	0.154	0.349	0.162
B	0.330	0.113	0.159	0.124
C	0.370	0.081	0.078	0.054
D	0.239	0.071	0.096	0.052
E	0.169	0.115	0.169	0.086

Finally, Lidén *et al.* (2008) also examined the effect of intense coin handling of 25 coins (Swedish 1 krone, 75% Cu, 25% Ni; or European 2 euro, see above) for 1 hour on nickel transfer to fingers and palm of the hand, although their measurements were of areal concentrations on small portions of the fingers and palms. They demonstrated average concentrations on the most exposed[12] parts of the fingers (thumb, index, and middle finger) ranging from 0.94 to 3 μg/cm^2, within the range expected by extrapolation from the observations of Staton *et al.* (2006) who measured an average of 22 ng/cm^2 averaged over the whole thumb and forefinger (about 100 cm^2, including the dorsal sides) after 2 minutes handling of a British 20 p coin.[13]

5.1.2. Application to lead transfer from guitar strings

The measurements obtained from handling of coins discussed in Section 5.1.1 show that transfer of metals to fingers occurs quantitatively in proportion to the metal concentration on the surface of the coins, at least for reasonably hard alloys of copper, nickel, and zinc. The alloys of interest here are primarily brass and phosphor-bronze, together with tin plating, with the metal of interest (lead) being a trace impurity. For all these materials, the rate of transfer of lead will be in

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[12] The volar (palmar) aspects of the fingertips (2 cm^2) were sampled.

[13] 22 ng/cm^2 × 60 mins/2 mins = 0.66 μg/cm^2. This should probably be doubled to 1.3 μg/cm^2 for comparison with Lidén *et al.* (2008) to account for inclusion in the area average of the less exposed parts of the fingers such as the dorsal surfaces.

proportion to the surface wear rate of the base alloy; and since the transfer of interest is from the bulk material (surface metal films picked up from other sources are not at issue here) the transfer rates and quantities corrected to 100% metal in Section 5.1.1 can be pro-rated to the lead fraction in the base metal.

The only metal transfer rates (in alloys, but separately corrected to 100% of each metal) estimated in Section 5.1.1 where the composition of the surface film was actually measured were initially in the range 0.2 to 1 μg/sec to three fingers (Table 3) and for all three metals (Cu, Ni, Zn). However, based on the amount of metal removed by polishing, such transfer rates could only continue for a few minutes at most, before the easily transferred (and easily leached) surface materials is depleted. After some polishing, the transfer rates were between 1/4 and 1/50 of the initial rate, and further polishing would presumably remove the final traces of the easily removed oxide or corrosion product films (see Section 5.3). Other experiments apparently measured rates in the same ranges that depended on the surface conditions of the coins tested, but the surface conditions were not well characterized.

The initial transfer rate will depend on the area of contact between fingers and metal surface, and presumably also on pressure, sweating rate, surface roughness, surface softness, oxidation state of the metal at the surface, and other unmeasured factors. However, because of depletion of the easily transferred materials, the transfer rate will subsequently decline substantially. The total amount of material transferred to the fingers during any playing session will not substantially exceed the amount of such easily transferred material, probably not much more than the amounts shown in Table 2. Using the facial surface areas of the coins in question[14] and the total amount of easily transferred material given in Table 2, the total metal content per unit surface area in easily transferred material is given in Table 7

Table 7 Metal content per unit surface area in easily transferred material.

	2 franc	2 euro	
Ni	12	5	μg
Cu	13	38	μg
Zn	2	8	μg
Total	27	51	μg
Total facial surface area	11.0	10.42	cm^2
Total metal content/unit area	2.5	4.9	$\mu g/cm^2$

It is not clear on what time scale the easily transferable material would re-form after removal (*e.g.* by polishing). This would require reformation of the oxide and other corrosion product

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[14] The relief on the surface of the coins, and the rim areas, are here ignored. Ignoring the rim results in an overestimate of the amount of metal content/unit area that may be easily transferred. The effect of relief on the surface is likely to be complex, but the additional frictional contact with high spots should largely cancel the reduced contact with of low spots.

films on the surface. To be conservative, it is here assumed that the easily available material is re-formed daily or more often, such that 50 μg/cm^2 metal content is available for transfer to fingers. This choice is clearly higher than measured by polishing of coins by Fournier and Govers (2003), but accounts for the potential extra material not removed by such polishing; it also matches the wipe test results for the heaviest gauge tin-plated steel strings tested by @@ (see Section 3.2 and Table 8).

For right-handed guitar players,[15] the fingers of the left hand continually hold strings under pressure against the frets, while the right hand is used to pluck the strings (or uses a pick to pluck the strings). The volar surfaces of all ten fingers may thus contact the strings, but palm contact is less frequent and minor (*e.g* for the right hand only when damping all the strings to interrupt playing). The contact is not deliberately rubbing, although fingers of the left hand may rub along the strings when changing chords and the right fingers will rub as the string is plucked. The surface area contacted will be fairly small (smaller than the contact area of fingers with coins), because of the narrowness of the strings. The total area of the strings contacted is, on average, less than half the scale length (the vibrating length of the string) of typically 25 inches — the right hand generally plucks in a length of just an inch or so, while it is rare for frets beyond 1/2 the scale length to be reached (causing the string to sound an octave or more higher than its open note).

A typical guitar is strung with 3 plain strings (tin plated steel) and 3 wrapped strings (phosphor-bronze, brass, or nickel-plated steel wrapping). Table 8 shows, for each of the 6 strings a calculation of the maximum total daily amount of transferable metal content, and the total amount of lead transferable to fingers, using the quantities described and assuming daily extensive contact with the whole length of the strings, for a guitar strung with "Mega Heavy" strings (to maximize the estimated surface areas; the average user will use thinner strings).[16]

Table 8 Calculation of maximum potential amount of lead transferred to fingers.

Type of string	Tin plated	Tin plated	Tin plated	Wrapped	Wrapped	Wrapped	Units
Diameter of string	0.013	0.017	0.026	0.036	0.046	0.056	inches
Scale Length	25	25	25	25	25	25	inches
Area of string	6.6	8.6	13.2	18.2	23.3	28.4	cm^2
Total available metal	329	431	659	912	1165	1419	μg
Maximum lead fraction	200	200	200	500	500	500	ppm
Maximum lead transfer	0.066	0.086	0.132	0.456	0.583	0.709	μg/day

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[15] Switch left and right in what follows for left-handed players.

[16] In Table 8, the corrugation of the surface of a wrapped string is ignored in calculating the surface area; skin in contact will not completely follow the corrugations, and may actually be in contact with less area than calculated.

The overestimated amount for potential amount of lead from the full length of all 6 strings is thus 2 μg/day. As mentioned just below Table 7, the estimate in Table 8 for the heaviest gauge tin-plated steel string (0.026 inch diameter) matches the wipe test result (Section 3.2);[17] but the Table 8 estimate for the heaviest-gauge wrapped string is far higher (by a factor of at least 10) than the wipe test results for phosphor-bronze or brass wrapped strings.

Since at most about 1/2 the length of the strings would be contacted daily, the estimated transfer rate of lead to both hands is then less than 1 μg/day.

Table 4 shows that to remove the easily transferred material required 30 seconds or more of rubbing contact. We are here assuming removal of 10 times that amount of material per day, which at the observed initial transfer rates would take 10 times longer, or at least 5 minutes of rubbing contact; and probably longer because the transfer rate will decrease as material is removed. We here assume sufficient contact with 1/2 the length (an octave range) of the strings, requiring about 5 minutes of rubbing contact with each portion of each of the 6 strings. That requires that each fret position of an octave worth (12 fret positions) of each of 6 strings be held in position (and rubbed) by a finger for 5 minutes,[18] for a total of 6 × 12 × 5 fret-position-minutes, or 360 fret-position-minutes; and to gain intimate contact with the whole surface area of the string (as assumed here) requires about twice that in order to contact the back side of the string (which would require the string to be rolled over during fingering). Fingering a single string at a time, this would take 12 hours; but simultaneous fingering of multiple strings is common, reducing the required time to perhaps 4 or 5 hours per day. However, it is clear that such extreme amounts of contact can be achieved only by dedicated playing over many hours per day.

5.2. Ingestion exposure to lead from guitar strings

Lead transferred to fingers may be absorbed by hand-to-mouth transfer and subsequent ingestion. The hand-to-mouth exposure discussion of the OEHHA (2008) fishing tackle guideline indicates that OEHHA believes that approximately 50% of the lead on about 20 cm^2 of the hand (about the area of one side of one finger) may be ingested in each hand-to-mouth contact.

For musicians playing guitars, the most contaminated area of the hand will be the volar surfaces of fingers; and such musicians may lick those surfaces (*e.g.* in order to aide in turning of pages of music). For the purposes of this evaluation, therefore, it is assumed that a guitar player may lick the contaminated surface of one finger (the same finger each time), and hence ingest the entire lead content on that finger, or 1/10 the lead on all 10 fingers. The frequency of such licking is irrelevant (provided it is high enough), since the rate-limiting step is contact with the guitar strings (see Section 5.1.2). It is likely that the contamination will be different on left and right

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[17] The wipe test wiped the full length of the string supplied, which is longer than the scale length when strung on a guitar.

[18] This implicitly assumes that the whole length of a string between fret positions is rubbed during holding of the string at a fret position, a probable overestimate of the amount of string in intimate contact with the finger. There will also be some string rubbing as the fingers move between fret positions, but that will be light and rapid rubbing.

hands,[19] with the left hand being most heavily contaminated since it may contact a greater area of the strings. However, it is more likely that the right hand finger will be the one licked and used to turn the pages of music, since the left hand will at that time be used to hold the guitar in place, so that using the average lead content of all the fingers will be an overestimate. The maximum ingestion rate of lead is thus estimated to be at most 1.0/10 = 0.1 μg/day.

It is possible that children under the age of about 6 might ingest a larger fraction of the lead on their hands. However, children are unlikely to be playing the instruments in question here (full-size electric guitars); and even if they did, or if they played smaller guitars strung with the strings at issue, they will not be exposed to the same extent. It was shown in Section 5.1.2 that to reach a transfer of less than 1 μg/day to the hands would require playing for 4 or 5 hours per day, and playing for less time would result in a pro-rated smaller transfer. Thus even with 1 hour/day of playing, and with 50% absorption of all lead on their hands, children's ingestion rate would be less than about (1.0/4) × 0.5 = 0.125 μg/day.

5.3. Dermal absorption exposure of lead from guitar strings

Dermal absorption of lead transferred to the surface of the skin has been observed for some chemical forms of lead. Stauber *et al.* (1994) indicate that lead carbonate was not observed to penetrate the skin, whereas penetration was detectable for lead, lead oxide, lead acetate, and lead nitrate. A quantitative estimate of 29.5% dermal absorption (measured as the loss from the applied material) was obtained for lead nitrate applied under extreme conditions (24 hours occlusive contact with the forearm), but no quantitative estimates were obtained for other chemical forms.

The chemical form of corrosion due to synthetic sweat of alloys of Cu, Ni, and Zn was investigated by Colin *et al*. (1999). They observed that the surface corrosion layers were primarily composed of copper and nickel products, primarily oxides and hydroxides with included chloride anions. The relevant form of lead rubbed from the similar alloys at issue here is thus likely to be metallic lead or lead oxide.

Filon *et al*. (2006) measured *in vitro* dermal penetration by lead oxide using human skin samples. After 24 hours application of 5 mg/cm^2 of lead oxide in synthetic sweat, penetration through intact skin was less than 0.2% of the applied lead oxide. At the end of the experiment, the skin itself (after mild rinsing) retained about 17% of the applied lead oxide, although other experiments (of shorter duration) indicated that washing with soap removed most of this (<2% of the applied lead oxide remained after washing with soap after a 30 minute application). It is likely that most of the lead retained in the skin even after the 24 hour application was in the surface layer and would have been readily removed by washing with soap. For example, Sun *et al*. (2002) demonstrated using tape stripping that even 12 hours after last exposure and after hand washing with soap followed by ethanol cleaning, approximately 1/3 to 1/2 the lead remaining in the exposed (dorsal hand) skin of heavily exposed battery workers lay in the upper two of ten skin layers, about a two- to four-fold excess compared with what would be expected from a linear gradient through the skin. Thus even after extensive washing of the surface, a large

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[19] Switch left and right in what follows for a left-handed player.

fraction of the lead in skin was still in the surface layer. If in the Filon *et al*. (2006) experiment it is assumed that only the applied lead oxide that entered the skin is relevant to absorption, absorption of lead oxide would be about 2% (*i.e.* of the lead entering the skin, about 2% was absorbed over the 24 hours of the experiment).

Sun *et al*. (2002) also demonstrated that in rats, lead absorption through the skin (as measured by urinary excretion) varied with chemical form, with absorption rates in the order lead naphthenate > lead nitrate > lead stearate > lead sulfate > lead oxide > lead powder. Compared with lead nitrate, lead oxide dermal absorption in rats was 15.7% and lead powder 6.5%. Applying the relative absorption observed in Sun *et al*. (2002) in rats to the 29.5% maximum absorption seen in 24 hours for lead nitrate by Filon *et al*. (2006) in humans gives estimates of 4.6% absorption for lead oxide, and 1.9% for metallic lead, assuming 24 application with no washing.

As an upper bound, it is here assumed that absorption of the lead rubbed from guitar strings might be as high as 4.6%, leading to an overestimate of approximately 0.046 μg/day.

5.4. Total exposure to lead from guitar strings

Summing ingestion and dermal exposures, total exposure from lead in guitar strings would be less than 0.15 μg/day, and perhaps as high as 0.17 μg/day in children under 6. These overestimates are substantially below the MADL level of 0.5 μg/day, and *ipso-facto* lower than the NSRL of 15 μg/day, even without taking account of averaging over non-playing days.

5.5. Other operations claimed to result in exposure in the Notice

The Notice of Violation (Footnote 1) claims potential exposure to employees when the guitar strings are (without limitation) “manufactured, used, packed, unpacked, labeled, arranged, installed, operated, cleaned, stocked, stored, repaired, or otherwise handled.” However, the guitar strings are not manufactured in CA (and there are no manufacturing facilities in CA). The strings are packed by @@, usually in pairs (strings 1 & 4, 2 & 5, or 3 & 6) in paper envelopes, so there is no exposure during any packing or unpacking operations; the strings are never removed from the envelopes until the final user strings his or her guitar. Indeed, handling must be avoided to maintain the appearance of the product and avoid corrosion; the envelope paper is specially treated to prevent corrosion for just this reason. Similarly, there is (and should be) no contact during any labeling, arranging, stocking, storing, or other handling, because all such handling is of the strings within their envelopes, preventing any skin contact. The only contact may occur if store employees provide the service of string installation (*i.e.* stringing a customer’s guitar). However, such contact would be less extensive and for less time than for the professional musician discussed above, so any lead absorption would be less. Finally, guitar strings are not repaired but replaced, and cleaning of guitar strings is done, if at all, by the guitar owner. Such cleaning involves wiping with rags, paper towels, or similar materials that are either dry or moistened with a cleaning agent, a procedure that does not involve skin exposure exceeding that while playing.

The Notice of Violation (Footnote 1) also contends that a player using a pick may put the pick in his or her mouth. However, this potential exposure route will result in substantially less exposure than estimated above because a pick will collect less metal from the string (because of lower surface area in contact with the string, and absence of sweat and grease to corrode the string and hold lead-contaminated material on the pick). Further, the surface area of a pick is considerably smaller than the surface area of the finger assumed to be licked in the discussion above.

6. Conclusion

A cursory examination of exposure to lead from guitar strings suffices to indicate that such exposure would not exceed the MADL (hence also the NSRL). More detailed examination of potential pathways of exposure shows that an average user of @@ guitar strings, whether an amateur or professional musician, would have an intake of lead due to that use that is substantially smaller than the MADL of 0.5 µg/person/day (using worst case estimates for all pathways combined), and *ipso facto* below the lowest lead NSRL of 15 µg/person/day.

7. References

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