

Headphones and Other Risk Factors for Hearing in Young Adults

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Abstract

Background: Personal listening device (PLD) use with headphones is increasing in young adults and in most listening environments occur in background noise. Headphone choice can be important because certain headphones are more effective in limiting background noise than stock earbuds. Binge drinking, marijuana, and hard drug use have also been associated with high-volume PLD use. The purpose of this study was to explore the relationship between preferred headphone type, listening level, and other health risk behaviors. **Methods:** Two-hundred and twenty undergraduates were recruited and completed a PLD use and risk behavior survey. Survey data included self-reported alcohol and marijuana use. Bilateral otoscopy, tympanometry, and pure-tone threshold testing (0.25–8 kHz) were completed. Participants listened to one hour of music using preferred headphone type with a probe microphone in the ear canal to measure equivalent continuous sound level (LAeq). **Results:** Mean LAeq was similar for the three types of headphones used. Participants who reported higher amounts of drinks per month and smoking marijuana within the last month had significantly higher LAeq levels than those who reported lower amounts of drinks per month and not smoking marijuana in the last month. There was no significant interaction between headphone type and reported drinks per month or marijuana use. **Conclusion:** Young adults with normal hearing who have higher preferred listening levels also reported more alcohol and marijuana use, although headphone type was not associated with any of these variables.

Keywords: Alcohol, hearing, headphones, marijuana, risk factors, young adults

INTRODUCTION

Over 75% of Americans have a smartphone, a percentage that has more than doubled since 2011, with 92% of young adults, aged 18–29 years, reporting smartphone use.^[1] Since these devices contain music storage and streaming capabilities, the use of headphones with smartphones, or personal listening devices (PLDs) in public spaces is common.^[2,3] Both excessive volume and duration of PLD use lead to hearing damage,^[4,5] and given the capability to play more content for longer periods of time due to increased accessibility and better battery efficiency, PLD listening opportunities grow longer every day. And as PLD use often occurs in a loud environment such as a bus or subway train, where background noise can reach 74 dBA and 87 dBA respectively,^[6,7,8] volume increases by listeners are expected, leading to a higher risk of hearing damage.^[4]

Headphone type is an important consideration for determining volume use; traditional stock earbuds rest

loosely on the edge of the ear canal and therefore not fit snugly, allowing for background noise to enter the ear canal in addition to the music. Earbuds are also sold as bundled accessories with most PLDs and smartphones on the market and, in conjunction with in-the-ear models, make up 56% of global headphone sales.^[9] Given the affordability, availability, connectivity, and convenience that earbud headphones provide, they are the most prevalent headphone type that young adults use with regularity. Earbuds fit more loosely compared to better encased insert headphones, and young adults using earbuds

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tend to set higher preferred PLD listening levels in both quiet and background noise conditions.^[10,11] Hodgetts *et al.*^[10] noted significant variability related to the effects of headphone type and the external environment, suggesting acoustic leakage as a major factor in preferred listening level. While earbuds provide a safer environmental listening experience that allows better access to outside sounds, the question of additional sound level over longer listening sessions possibly affecting hearing compared to other headphone types is of concern.

There is increasing research on whether or not young adults are listening to PLDs at dangerous levels for extended periods of time.^[2,12] An objective method for obtaining preferred listening levels in young adults is accomplished by using probe microphone measurements, as they allow for placement approximate to the most medial section of the external auditory canal, and can therefore provide an accurate recording of acoustic sound immediately prior to reaching the tympanic membrane.^[2,4,10-14] Because everyday listening environments regularly feature background sounds, listening to PLDs is a way to mitigate their presence.^[7,8] Background noise caused by the surrounding environment has been shown to be a factor in preferred listening level, as ambient sound competes with the input signal from headphones.^[4,10,11] Two of the most commonly reported settings for PLD use by adolescents and young adults is during exercise and while on college campuses.^[2] For adolescents who use PLDs in active settings, Hodgetts *et al.*^[15] found that physical exercise in addition to increased background noise caused listeners to report increased volume of their PLDs compared to listeners coming from quiet environments like libraries.^[10,15] This research has provided a foundation in the evaluation of how PLD use might affect hearing health in adolescents and young adults.

Regarding the association of hearing health and decision-making in a broader sense, there are limited data on the relation between music listening habits and health-risk behaviors. Self-reported marijuana use, binge drinking, and hard drug use have all been significantly associated with high-volume PLD use, along with the likelihood of attending events that feature potentially hazardous sound levels (i.e., clubs, concerts).^[6] Vogel *et al.*^[6] found that marijuana users report more frequent PLD listening sessions at high levels, while heavy alcohol users report higher exposure to hazardous sound levels at bars and clubs. Alcohol consumption can also affect audiometric thresholds, leading to temporary threshold shifts after consumption takes place.^[16,17] These studies demonstrate the fact that young adults who report high-volume music also report other health-risk behaviors. What is lacking in the current literature is how these health risk behaviors are associated with hearing health risk factors.

By combining research on heavy use of PLDs among young adults, listening levels during PLD use, and health-risk behaviors, the aim of this study was to explore the

relationship between headphone type, listening level, and risk-taking. The specific research questions were: 1) What are the preferred listening levels for three types of headphones (earbuds, inserts, and circumaurals) in young adults with normal hearing?; 2) How do third-octave band data vary in frequency response characteristics for the three types of headphones?; and 3) Is there an association between preferred listening level and any risk-taking behavior and if so, does preferred headphone type correlate to other behavioral risk factors?

METHODS

Subjects

Since July 2016, undergraduates between the ages 18-35 years have been recruited from various undergraduate courses (e.g., Social Work, Exercise and Nutritional Sciences, and Speech, Language, and Hearing Sciences) at San Diego State University (SDSU) to be enrolled in a larger study titled, Risk Factors for Hearing Loss in Young Adults. For the purposes of the current study, 220 participants, 56 young adult men (mean age = 20.9 years; SD = 3.1 years) and 164 young adult women (mean age = 21.0; SD = 2.7 years), all of whom reported normal hearing at the time of study entry, had complete data.

Self-reported risk factor survey

Informed consent was obtained after testing procedures were explained although, given the nature of certain sensitive survey questions, signed consent was not required and all study data were anonymous. Research assistants administered The Risk Factors Survey,^[12] a personal music system use and risk behavior survey that identifies possible risk factors for hearing loss that includes preferred listening level and duration of music listening using preferred headphones. Two of the closed-set survey questions of interest in this study were: "For a typical day, what is the most common volume used during this day?" "Low", "Medium/Comfortable", "Loud", or "Very Loud"; and "Do you listen to your personal music system at a volume where you. . ." "easily hear people", "have a little trouble hearing people", "have a lot of trouble hearing people", or "cannot hear people".

The survey also included information about social risk factors including alcohol, marijuana, and substance (i.e., prescription medication) use. Participants were provided with information about standard drinks (e.g., 12-ounce can/bottle/glass of beer or cooler, 5-ounce glass of wine, or a drink containing 1 shot of liquor), along with timeline information such as habitual consumption routines and maximum drink consumption over 30 days prior to completing survey.

Pure-tone threshold assessment

Participants in this study underwent binaural otoscopy, tympanometry, and audiological testing to assure no evidence of occluding cerumen. Hearing was assessed

using a GSI 61 clinical audiometer with TDH-50P headphones. Pure-tone air conduction thresholds were recorded in a double-walled sound booth within the Recreational Noise Exposure and Hearing Loss Lab at SDSU. Octave frequencies 0.25 through 8 kHz in both ears for all participants were obtained and normal hearing was confirmed (≤ 25 dB HL) with Type A tympanograms.

Probe microphone recording

Each participant remained in the sound booth, and then listened to one-hour of music while preferred listening levels were recorded using a probe microphone inserted approximately 28 mm into the participant's randomly chosen test ear. A marker on the probe microphone measured to 28 mm was placed at the intertragal notch to confirm the insertion depth. A small piece of medical tape on the ear lobe was used to further secure the probe microphone in place. The probe microphone system was connected to a Motu audio interface in order for acoustic data to be transmitted to and stored by the Electroacoustics Toolbox software (Version 3.8.3; Faber Acoustical, LLC) on an Apple iMac (Apple, Inc.) computer. Participants were asked to bring their personal headphones for this study. Participants brought one of four types of headphones to this study: Apple iPhone earbuds that rest loosely on the edge of the ear canal; traditional stock earbuds from other manufacturers (i.e., Skullcandy) that rest loosely on the edge of the ear canal; in-the-ear inserts that fit deeper inside the canal; or supra-aural, over-the-ear headphones.

The participant placed their headphones in and proceeded to listen to one-hour of music of their choice at their preferred listening level, but they could change tracks and adjust the volume as long as they continued to listen to music for the hour. The purpose of providing a flexible listening scenario for one consecutive hour was to represent a real-world scenario where personal listening device use would potentially start and stop regularly. The overall dB SPL of the music sample, averaged over one hour, was recorded using the Sound Level Meter and Octave Band Analyzer functions from the Electroacoustics Toolbox. The Sound Level Meter function was used to measure A-weighted equivalent sound level (L_{Aeq}) averaged over one hour of music; these data were exported for offline analysis that included correcting for diffuse-field and a closed canal (ADL_{Aeq}). The Octave Band Analyzer program converted the recorded acoustic signal (i.e., one hour of music) into one-third octave data between 0.125 and 8 kHz.

Risk factor statistical analyses

Preferred listening level variable definitions. PLD system volume use was categorized using two definitions in a way that has been reported previously.^[12] Briefly, participants who reported low and medium/comfortable volume were defined as *Non-Loud* and those who reported loud and very loud volume were defined as *Loud*. Based on

responses to the question about whether they can hear others when listening to their PM system, participants who reported they could easily hear people or have a little trouble hearing people were as *Can Hear*. And those who reported either have a lot of trouble hearing people or cannot hear people were defined as *Cannot Hear*.

Alcohol variable definitions. When determining alcohol consumption over prior 30 days, drinks per month (DPM) was calculated by the reported number of days having a drink containing alcohol multiplied by the reported number of drinks usually consumed each time. Those who did not report drinking in the last 12 months and those who did not report drinking in the last 30 days were defined as No DPM. Low and high DPM were defined using the median value of the continuous drinks per month data.

Marijuana variable definitions. Questions pertaining to lifetime marijuana use, along with questions about use over the 30 days prior to completing survey were answered. Marijuana use per month (MARIM) was calculated using the number of times the participant reported using marijuana during the last 30 days. Those who never used marijuana or did not report using marijuana in the last 30 days were defined as No MARIM. Low and high MARIM were defined using the median value of the continuous uses per month data.

Chi-square analyses were used for all categorical data. An analysis of variance (ANOVA) was used to first evaluate any differences in preferred listening level (ADL_{Aeq}) between the three types of headphones. This model was adjusted for sex and age and appropriate interaction terms were also included in the model. Additional ANOVAs were used to evaluate the associations between each risk factor variable (i.e., DPM, and MARIM), evaluated separately, and ADL_{Aeq} while adjusting for sex, age, and headphone type. The interaction terms for the independent variables were also included in these analyses.

RESULTS

Self-reported volume use

The six participants who did not report using a PLD with headphones were not included in the hearing-related survey question analyses. Of the 214 participants with complete data, 74.3% ($n = 159$) were women, and 25.7% ($n = 55$) were men. Table 1 presents participant responses to relevant hearing-related survey questions for men and women. Men reported a statistically significant higher rate of "Loud" or "Very Loud" as most commonly used volume compared to women ($\chi^2(2) = 11.0$, $P < 0.05$); however, men and women had similar non-statistically significant responses in their ability to hear surroundings when using PLDs ($\chi^2(3) = 4.5$, $P > 0.05$). When these self-reported volume data were dichotomously defined between *Loud* and *Non-Loud*, men again had a statistically significant higher rate of *Loud* responses compared to women ($\chi^2(1) = 7.4$, $P < 0.05$).

When the self-reported volume data were dichotomously defined between *Can Hear* and *Cannot Hear* with regards to the ability to hear surroundings when using PLDs, men and women showed no statistically significant difference between the two categories ($\chi^2(1) = 1.8$, $P > 0.05$).

Behavioral risk factors

Alcohol. Table 2 shows self-reported alcohol and marijuana use for men and women. For those who reported drinking during the last 30 days (i.e., DPM), the median number of drinks was 14 and this number was used to define Low DPM (≤ 14 drinks) and High DPM (> 14 drinks). There were 62 participants (28.2%) in the No DPM group, 79 participants (35.9%) in both the Low and High DPM groups. Men had a slightly higher percentage of self-reported High DPM, but overall the percentages were similar between men and women [Table 2]. Of the six participants who did not report using a PLD, 5 of them were No DPM and the other participant was a low DPM.

Marijuana. Also in Table 2, there were 153 participants (69.6%) who did not report using marijuana during the past 30 days (i.e., MARIM). For those who reported using marijuana in the past 30 days, the median number of uses was two times; this was used to define low MARIM (≤ 2 times) and high MARIM (> 2 times). There were 35 participants (15.9%) who were high MARIM, while 32 participants (14.5%) were low MARIM. Men had a higher percentage of high MARIM (21.4%) compared to women (14.1%), but

there were fewer men ($n = 12$) compared to women ($n = 23$) in the same group. Of the six participants who did not regularly use a PLD, five of them had reported not having used marijuana over the past 30 days.

Preferred listening level

The overall mean preferred listening level ADL_{Aeq} measured from the hour-long recording across all participants ($n = 220$) was 72.8 dBA (SD = 10.8 dBA). Men had a statistically significant higher preferred listening level than women when listening to music in quiet background testing conditions ($F[1,213] = 6.52$, $P < 0.05$); men listened at an average of 4.6 dB higher than women, with men listening at a measured mean ADL_{Aeq} of 76.3 dBA (SD = 10.1 dBA) compared to the mean preferred listening level ADL_{Aeq} for women of 71.7 dBA (SD = 10.8 dBA). Table 3 shows the means, and standard deviations, for preferred listening levels of men and women by different headphone types. In men, those who used earbuds had a slightly lower mean preferred listening level and those who used circumaural headphones had the highest mean preferred listening level among headphone types. Conversely, women who used circumaural headphones had a slightly lower mean preferred listening level and women who used inserts had the highest preferred listening level among headphone types. Although there was a statistically significant effect for sex on preferred listening level, the sex-by-headphone type interaction ($F[2,213] = 0.21$, $P > 0.05$) was not statistically significant.

Table 1: Participant responses to the hearing-related questions of the risk factors survey by sex

Reported volume ¹	Men	Women	Total
Low/medium	27 (49.1%)	112 (70.9%)	139 (65.2%)
Loud	20 (36.4%)	42 (26.6%)	62 (29.1%)
Very loud	7 (12.7%)	5 (3.2%)	12 (5.6%)
Hear people ²			
Easily hear people	2 (3.6%)	20 (12.6%)	22 (10.3%)
Have a little trouble hearing people	36 (65.5%)	104 (65.4%)	140 (65.4%)
Have a lot trouble hearing people	10 (18.2%)	21 (13.2%)	31 (14.5%)
Cannot hear people	7 (12.7%)	14 (8.8%)	21 (9.8%)

¹Seven participants (five women, one man) reported not using a personal music system with headphones and one man could not recall volume use. ²Seven participants (five women, one man) reported not using a personal music system with headphones

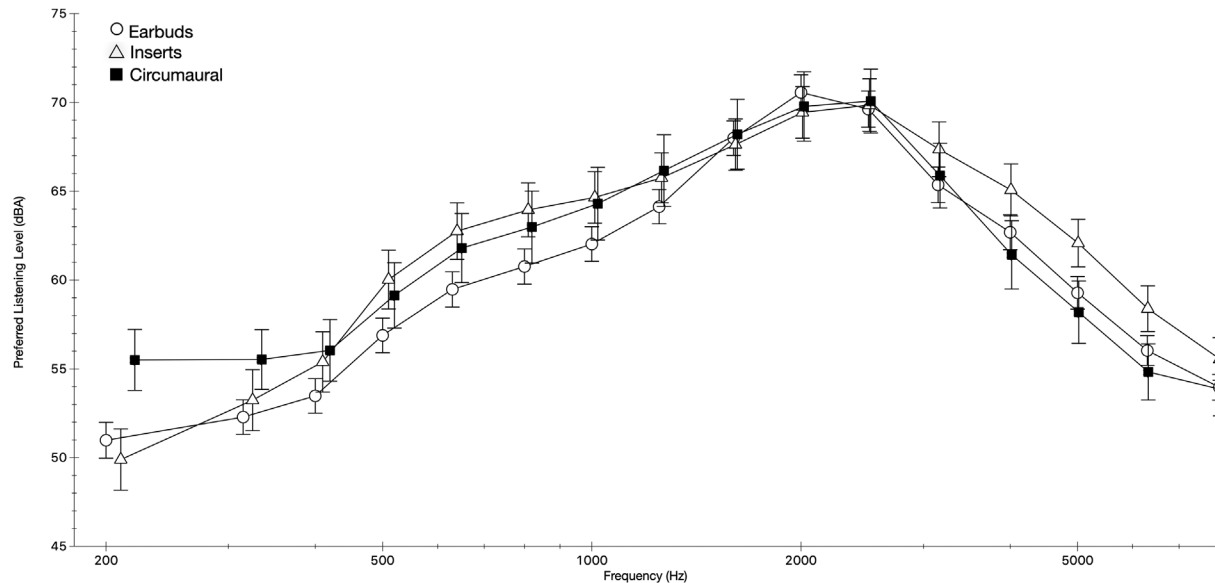
Table 2: Participant responses to the alcohol and marijuana use questions of the risk factors survey by sex

	Men ($n = 56$)	Women ($n = 164$)	Total ($n = 220$)
Drinking			
No DPM	17 (30.4%)	45 (27.4%)	62 (28.2%)
Low DPM (≤ 14 drinks)	18 (32.1%)	64 (37.2%)	79 (35.9%)
High DPM (> 14 drinks)	21 (37.5%)	58 (35.4%)	79 (35.9%)
Marijuana			
No MARIM	236 (64.3%)	117 (71.3%)	153 (69.6%)
Low MARIM (≤ 14 uses)	8 (14.3%)	24 (14.6%)	32 (14.5%)
High MARIM (> 2 uses)	12 (21.4%)	23 (14.1%)	35 (15.9%)

DPM, drinks per month; MARIM, marijuana uses per month.

Table 3: Means (and standard deviations) of preferred listening levels (ADL_{Aeq}) across headphone types by sex

	dBA ADL _{Aeq} (Standard deviation)			Overall mean ADL _{Aeq}
	Earbuds	Inserts	Circumaural	
Men (<i>n</i> = 56)	75.9 (10.1)	76.4 (6.2)	77.2 (12.9)	76.3 (10.1)
Women (<i>n</i> = 164)	71.3 (11.0)	73.2 (10.6)	70.7 (10.4)	71.7 (10.8)
Overall (<i>n</i> = 220)	72.4 (10.9)	73.9 (9.8)	73.0 (11.6)	72.8 (10.8)

**Figure 1:** Equivalent Continuous Sound Level (ADL_{Aeq}) means and standard errors, in dBA, for one-hour music listening across headphone types for frequencies 0.2–8 kHz. Earbuds (circles), Inserts (triangles), and Circumaural Headphones (squares)

Headphone types used among participants were evaluated to determine preference. Since there were only five stock earbuds used, Apple earbuds and other stock earbuds were combined into one group, representing 60% (*n* = 132) of all transducers, while 23.2% (*n* = 51) were inserts, and 16.8% (*n* = 37) were circumaural headphones. Headphones were provided for participants who did not report using PLDs with headphones, and therefore did not bring their own (*n* = 6). Of those six participants, three were provided with earbuds, two were provided with insert headphones, and one provided with circumaural headphones. The overall mean ADL_{Aeq} for earbuds was 72.4 dBA (SD = 10.9 dBA), for inserts, the mean ADL_{Aeq} was 73.9 dBA (SD = 9.9 dBA), and for circumaural headphones, the mean ADL_{Aeq} was 73.0 dBA (SD = 11.6 dBA). There was no significant difference for overall ADL_{Aeq} for headphone type ($F[2,213] = 0.16$, $P > 0.05$).

Preferred listening level data were also evaluated in one-third octave bands; ADL_{Aeq} was ± 5 –6 dB of each other across the three headphone types for frequencies 0.2–8 kHz. Frequency response curves for each headphone type are shown in Figure 1. Though there were no significant differences between headphone type overall level, there were slight variations among headphone types for 1/3 octave band data. Circumaural headphones had a greater mean level at

0.2 kHz, with an average of 4.5 dB higher than earbuds at that frequency, and 5.6 dB higher than inserts. Inserts also had slightly higher mean levels between 3 and 8 kHz compared to the other two transducer types, but with an essentially similar frequency response curve.

Combination of risk factors

Reported PLD use and alcohol. Survey questions pertaining to daily PLD listening habits and alcohol use are shown in Table 4. “Low” and “Medium” responses were combined in self-reported typical volume level data due to only two participants who reported “Low” volume use. Over 65% of participants (139 of 213) reported listening at either “Low” or “Medium” volume. Most of the participants reporting “Low/Medium” volume also reported alcohol use (102 of 139, 73.4%) in the past 30 days. More participants in the High DPM category (*n* = 7) reported listening to their PLDs at a “Very Loud” volume than those in the Low DPM category (*n* = 2), and those in the No DPM group (*n* = 3). Although the sample size was small, the High DPM category accounted for 58.3% of all participants (7 of 12) who reported that they listen at “Very Loud” volume.

There were 22 participants who reported that they could “Easily Hear People” while using PLDs, and 11 of those 22

Table 4: Participant responses to the hearing-related questions by risk factor

	DRINKING		
	No DPM	Low DPM	High DPM
Reported volume			
Low/medium (<i>n</i> = 139)	37 (26.6%)	60 (43.2%)	42 (30.2%)
Loud (<i>n</i> = 62)	17 (27.4%)	16 (25.8%)	29 (46.8%)
Very loud (<i>n</i> = 12)	3 (25.0%)	2 (16.7%)	7 (58.3%)
Hear people (<i>n</i> = 214)			
Easily hear people (<i>n</i> = 22)	6 (27.3%)	11 (50.0%)	5 (22.7%)
Have a little trouble hearing people (<i>n</i> = 140)	42 (30.0%)	52 (37.1%)	46 (32.9%)
Have a lot trouble hearing people (<i>n</i> = 31)	6 (19.4%)	9 (29%)	16 (51.6%)
Cannot hear people (<i>n</i> = 21)	3 (14.3%)	6 (28.6%)	12 (57.1%)
Marijuana			
	No MARIM	Low MARIM	High MARIM
Reported volume (<i>n</i> = 213)			
Low/medium (<i>n</i> = 139)	106 (76.3%)	17 (12.2%)	16 (11.5%)
Loud (<i>n</i> = 62)	36 (58.0%)	13 (21.0%)	13 (21.0%)
Very loud (<i>n</i> = 12)	4 (33.3%)	2 (16.7%)	6 (50.0%)
Hear people (<i>n</i> = 214)			
Easily hear people (<i>n</i> = 22)	18 (81.8%)	0 (0%)	4 (18.2%)
Have a little trouble hearing people (<i>n</i> = 140)	101 (72.1%)	21 (15.0%)	18 (12.9%)
Have a lot trouble hearing people (<i>n</i> = 31)	20 (64.5%)	8 (25.8%)	3 (9.7%)
Cannot hear people (<i>n</i> = 21)	8 (38.1%)	3 (14.3%)	10 (47.6%)

Table 5: Means (and standard deviations) for preferred listening levels (ADL_{Aeq}) across risk factors by headphone type

	Earbuds	Inserts	Circumaural	Overall mean ADL_{Aeq}
Drinking				
No DPM	72.6 (12.4)	72.1 (9.3)	68.2 (10.4)	71.7 (11.2)
Low DPM (≤ 14 drinks)	70.3 (10.0)	73.6 (7.4)	72.2 (11.5)	71.3 (9.7)
High DPM (> 14 drinks)	74.3 (10.6)	76.4 (12.7)	77.4 (11.6)	75.3 (11.1)
Marijuana				
No MARIM	70.9 (10.8)	72.7 (8.6)	72.1 (11.5)	71.5 (10.4)
Low MARIM (≤ 14 uses)	75.4 (8.8)	74.2 (12.2)	75.4 (16.9)	75.2 (10.2)
High MARIM (> 2 uses)	75.4 (12.4)	79.9 (13.1)	75.6 (9.4)	76.4 (11.9)

were also Low DPM (50%). The largest group was those who reported that they “Have a Little Trouble Hearing People” during PLD use (140 of 214, 65.4%). No DPM, Low DPM, and High DPM all had similar percentages across that response (30%, 37.1%, and 32.9%, respectively). Most of those participants who indicated that they “Have A Lot Of Trouble Hearing People”, as well as those who reported “Cannot Hear People” during PLD use reported as High DPM (51.6% and 57.1%, respectively). Participants from both of these categories account for 24.3% of the sample size.

Reported PLD use and marijuana. Survey questions pertaining to daily PLD listening habits and marijuana use are also shown in Table 4. More High MARIM participants (*n* = 6) reported listening to music at a “Very Loud” volume than those who were Low MARIM (*n* = 2), and No MARIM (*n* = 4). Again, there is a small sample size for “Very Loud” volume use, 50% of all participants were in the high MARIM group.

Most of the participants reported that they “Have a Little Trouble Hearing People” during PLD use (65.4%), across all of the MARIM categories. Eighteen of the 22 (81.8%) participants who reported being able to “Easily Hear People” around them reported No MARIM, though only 22 (10.3%) of the 214 participants reported this. Those who reported that they “Have a Little Trouble Hearing People” or “Have a Lot of Trouble Hearing People” also reported not having used marijuana in the past 30 days (72.1% and 64.5%, respectively). Almost half (10 of 21, 47.6%) of High MARIM users reported that they “Cannot Hear People” during PLD use, although 38.1% (8 of 21) of No MARIM users reported that they “Cannot Hear People” during PLD use.

Preferred listening level and alcohol. Mean preferred listening level across levels of risk factor use can be seen in Table 5. Those defined as High DPM had a higher mean ADL_{Aeq} (75.3 dBA, SD = 11.1 dBA) than those defined as

Low DPM (mean = 71.3 dBA, SD = 9.7 dBA), as well as those who reported No DPM (mean = 71.7 dBA, SD = 11.2 dBA). This difference was statistically significant ($F[2,219] = 3.81$, $P < 0.05$). There was no statistically significant interaction between headphone type and reported DPM for ADL_{Aeq} ($F[4,219] = 1.05$, $P > 0.05$).

Preferred listening level and marijuana. Mean preferred listening level was higher in participants who reported any marijuana use in the past 30 days. The mean ADL_{Aeq} of those participants defined as Low MARIM (mean = 75.2 dBA, SD = 10.2 dBA) and High MARIM (mean = 76.4 dBA, SD = 11.9 dBA) were higher than those defined as No MARIM (mean = 71.5 dBA, SD = 10.4 dBA). The preferred listening difference across marijuana exposure categories was borderline statistically significant ($F[2,219] = 2.98$, $P = 0.053$). There was no statistically significant interaction between headphone type and reported MARIM for ADL_{Aeq} ($F[4,219] = 0.39$, $P > 0.05$).

DISCUSSION

The aim of this study was to investigate the relationship between headphone preference, risk factors, self-reported PLD listening habits, and objectively recorded PLD listening exposure in young adults. Through survey data, men reported greater volume use, with more men seeking a “Loud” volume (36.4%, 20 of 54 participants) compared to women (26.6%, 42 of 159 participants) when listening to music on a daily basis. Women preferred a “Low/Medium” volume for daily listening compared to men, 70.9% and 49.1%, respectively. Both men and women reported similar ability in hearing surroundings, regardless of headphone volume. For PLD use over an hour, men listened at an average 4.6 dB higher than women. There was no significant difference in listening levels across headphone type. In terms of risk factors considered, men reported slightly higher alcohol and marijuana use compared to women. Participants in the High DPM group reported listening at “Loud” and “Very Loud” levels more than those who reported some or no drinking, while participants in the High MARIM group reported listening at only “Very Loud” levels more than those who reported some or no marijuana use. Most participants reported having a “Little Trouble Hearing People” while wearing PLDs, regardless of reported drug and alcohol use. However, most of those who reported that they “Cannot Hear People” while wearing PLDs also reported higher drug and alcohol use.

In the current study, there was a statistically significant sex difference for preferred listening level. Specifically, men listened at a significantly higher preferred level (76.3 dBA) compared to women (71.7 dBA). Other studies have reported this same association^[11,12]; Park *et al.*^[11] reported men listening at higher levels than women by approximately 3 dB in a quiet library environment, while Torre and Reed^[12] reported men listening at higher levels

than women by approximately 6 dB. In comparison, men in the current study listened at a higher mean level than women by approximately 5 dB. These studies all involved young adults enrolled at a university. More specifically, The current study included 220 participants (164 women 56 men), whereas Torre and Reed^[12] enrolled 160 participants (111 women and 49 men); Park *et al.*^[11] collected data in 52 student participants who were recruited when exiting the library (15 women and 37 men). Even with differences in sample sizes, the sex effect where men have significantly higher preferred listening level is consistent.

Another aim of the current study was to assess the role that headphones play in risk behavior, and how risk behaviors and other factors related to preferred listening level among participants. Earbuds were the most frequently used transducer in the study, with 60% of participants using them during objective recording, indicating regular use over the other styles of headphones. Inserts were used by 23% of the sample, and circumaural headphones were used by 17%. There was little variation in frequency response among headphone styles; and while there was small variability in the mean one-third octave band data across the frequencies measured between headphone type, there was no significant difference in overall measured preferred listening level between headphone type in quiet. There were no interactions between headphone type and either DPM or MARIM for preferred listening level. Based on these analyses, headphones were not an additional risk factor in young adults with normal hearing.

Instead of a direct cause-and-effect relationship featuring a scenario with alcohol or marijuana and threshold shifts, data collected from this study are consistent with Vogel *et al.*,^[6] such that in both studies specific risk factors were evaluated as they related to reported volume preference. Vogel *et al.*^[6] surveyed 944 young adults and found that reported “risky” music-listening behavior (>89 dBA for 1 hour), was directly correlated with alcohol and drug use. Marijuana users reported more frequent PLD listening sessions at high levels, while heavy alcohol users reported higher exposure to hazardous sound levels at bars and clubs. Participants in the current study who reported more alcohol and marijuana use also reported higher volume use. This study expands upon the findings of Vogel *et al.*^[3] by also including objective listening data such that self-reported alcohol and marijuana use generally corresponded to higher recorded preferred listening level.

The current study contributes new data to this area of research in terms of the objective preferred listening level data collected, analyzed, and compared to reports of subjective volume preferences. Self-reported marijuana and alcohol use over the past 30 days can provide an indication of lifestyle, and the more extreme users of those risk factors tended to listen to music in objective recordings at louder levels as well. Those who reported High DPM (>14 DPM) had significantly

higher ADL_{Aeq} measurements than those who reported Low DPM or No DPM, while those who reported any marijuana usage also had statistically significantly higher ADL_{Aeq} measurements compared to No MARIM. Those in combined low and high MARIM groups reported listening to music “Very Loud” at twice the rate compared to the No MARIM group, while High DPM participants reported listening to music “Loud” and “Very Loud” at almost twice the rate compared to No DPM and Low DPM participants. Self-reported volume use can be used as a predictor for objective measurements of PLD listening level,^[12] demonstrating an awareness by young adults. Because these participants choose to listen to their PLD at higher levels, they were likely aware of the risk involved, much like they were with alcohol and marijuana usage. It is unclear, however, whether young adults recognize the potential long-term risk of these factors while being involved in the heightened sensations from alcohol, drugs, and loud music.

All of the participants in the current study had normal hearing and pure-tone thresholds at enrollment. Thresholds were not obtained after the one hour of music, as change in hearing after music exposure was not the aim of the current study; change in DPOAEs after music exposure from the Torre lab has been reported elsewhere.^[14] The role that drugs and alcohol play in hearing health has been established in other studies.^[6,16,17] Upile *et al.*^[16] found that alcohol consumption can affect auditory thresholds. In that study, participants had audiometric threshold testing completed twice; once prior to alcohol consumption, and once after surpassing the United Kingdom’s legal driving limit of blood alcohol concentration of 30 μ /l. There was a mean threshold shift of 7 dB primarily at lower frequencies (0.25, 0.5, 1 kHz), with changes greater in women than in men. Kraaijenga *et al.*^[17] also reported drugs and alcohol as risk factors for thresholds shift, specifically for outdoor music festivals. In adults with normal hearing who attended a music festival without hearing protection, the reported use of alcohol, drugs, and the factor of being a male were all associated with temporary threshold shifts at 3 and 4 kHz; the shift was represented as an increase in threshold by a mean of 1.1 dB for reported quantity of alcohol, a mean of 6.0 dB for reported drug use, and a mean of 4.1 dB for being a male.^[17] Over long term marijuana use, Brumbach *et al.*^[18] found no significant difference in behavioral thresholds between marijuana smokers and non-smokers, though male smokers measured poorer DPOAE amplitudes at lower frequencies (<2 kHz) compared with male non-smokers. While behavioral thresholds were not different between smoker and non-smoker groups, the insignificantly poorer low frequency DPOAE measurements among marijuana smokers led researchers of that study to conclude that smoking marijuana may still negatively affect cochlear function. The limitations involved in this study include the conversion measures for free-field equivalency, the lack of a noise condition across the multiple headphone types, daily exposure variability, inaccurate reporting of

alcohol and marijuana use, and the sex distribution of the study’s sample. Among the different headphone types, the conversion used to calculate free-field equivalence adjusted specifically for earbuds. Since earbuds sit farther from the tympanic membrane than inserts, there is likely overestimation of preferred listening level for inserts based on this conversion. However, the small adjustment should not cause significant differences in responses between the transducers. One aim was to obtain preferred listening levels from different headphone types in quiet, but the importance of performance in background noise should not be understated. Earbuds, for example, are known for leaking sound both in and out of the ear canal; this requires users to increase volume to overcome environmental noise. While the participants in this study were allowed to adjust volume as desired for the one hour during the probe microphone recording to represent real-world listening, these findings were conducted in a quiet, sound-treated booth within an auditory laboratory space. A more accurate real-world listening situation would have included the presence of background noise. Noise conditions would have provided more accurate information in reflecting daily listening behavior, since primary headphone use occurs in transit with the presence of city and transportation sounds^[7,8,19] or in dynamic, active settings like the gym.^[2,15] Given that PLD use is a voluntary and convenient activity, daily usage is likely to vary both among young adults, and within those same young adults, leading to difficulty in determining the actual risk. Additionally, the irregularity of university students’ schedules may lead to erratic listening habits. There is also the possibility that participants may have modified their listening habits or the reporting of alcohol and marijuana use based on their involvement in the present study. And finally, the demographics of sex in this study skewed towards women, as men only accounted for a quarter of the participants. Though not ideal for a study meant to represent a population of young adults, the participating students were representative of the student body that comprises the SDSU College of Health and Human Services population.

The data from this study suggest that sex, as well as risk behaviors such as alcohol and marijuana, have an impact on preferred listening level and reported volume use in young adults, but that headphone type does not. Men reported louder listening habits than women, which was verified by objective measurements. Participants who reported higher drinking also reported listening at louder levels more than those who reported little or no drinking, while participants who reported higher marijuana use also reported listening at louder levels more than those who reported some or no marijuana use. When considering objective preferred listening level data, heavy drinkers are more likely to listen to music at louder levels than light drinkers, or those who do not consume any alcohol. Marijuana users are more likely to listen to music at louder levels than those not using marijuana. Considering these results, risk behaviors such as alcohol and marijuana may contribute to long-term effects on auditory function.

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Conflicts of interest

There are no conflicts of interest.

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