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LOMBARD EFFECT, AMBIENT NOISE AND WILLINGNESS TO SPEND TIME AND MONEY IN A RESTAURANT AMONG OLDER ADULTS

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ABSTRACT

Dining establishments are often characterized by high levels of background noise, which represents a barrier for an effective communication. This particularly affects people suffering from hearing problems. Moreover, noise levels exceeding normal conversational levels causes a subconscious phenomenon called the Lombard Effect, an involuntary tendency to increase the amount of vocal effort when talking in the presence of noise. The primary aim of the current study was to understand the effect of noise on vocal effort and speech intelligibility in a restaurant setting for adults over 60 years old with and without hearing loss. The secondary aim was to evaluate how their perception of disturbance in the communication, their willingness to spend time and money in a restaurant was affected by the varying levels of background noise. The results of this study showed background noise levels, lower than 50 dB(A), will allow the senior customers to minimize their vocal effort and to allow for more understanding than 50% of the conversation, even for those impacted by moderate to severe hearing loss. This limit will also keep the disturbance of the communication below 50% and the willingness to spend time and money in a restaurant over 50%.

1. INTRODUCTION

Prior to Coronavirus (COVID-19), for many, going out for a meal had become the new standard to spend time with family, friends, and conducting business [1]. Before the 1990's, "excessive" restaurant noise was considered insignificant to diners and critics, which added to the atmosphere of the eating establishment [2]. A restaurant's atmosphere is vital to keeping and enticing new patrons; by creating a connection between taste and sound, music selections can subconsciously cause the diners to increase their overall food and beverage consumption and bill at a restaurant [2-3]. Depending on the age group you ask, several individuals might recall the noisy environment more than the food [4]. This is especially problematic for everyone as dynamic background noise, such as restaurants [1], degrades the understanding of conversations. The relationship between noise and conversations contributes to an individual's overall "quality of life" (QOL). Quality of life has been defined to be the self-perception of life satisfaction, fulfillment, and happiness [5]. A key term when discussing quality of

life are "positive indicators," which translates into an object, person, or environment that is providing improvement to the individuals life [6]. QOL is important to the overall topic of the current study, as individuals place value on the luxury of dining out.

In recent years, there has been increased awareness towards the acoustics of eating establishments with the goal of improving speech intelligibility [7-8]. Restaurants are designed to look aesthetically pleasing and modernized, which often is portrayed with a lack of materials used to absorb sound. The lack of these materials tends to increase the overall noise level in the restaurant which has caused diners, critics, and audiologists to take notice [2, 4, 7-10]. In a survey by Zagat [11], individuals voted noise to be the second complaint of restaurants, followed by service [8]. However, when the survey was repeated, it revealed noise was now the first complaint of patrons [12]. With noise levels growing, restaurant critics have begun to carry sound level meters to evaluate the noise levels during their busiest times [2].

Restaurants have a wide range of noise during hours of operation. Typical restaurant noise can fluctuate throughout the course of an evening ranging from 65 dB(A) up to as high as 91 dB(A), which causes increased difficulty to be heard and understood by anyone in these extreme dining settings [1, 2, 4, 8, 10, 13]. While many restaurants noise levels have been recorded up to 85 dB(A) in recent years, there are several other dining facilities that may exceed this measurement and have not been recorded. These problematic levels affects not only the older adults, but also the whole of the restaurant industry who eagerly looks to entice new patrons with flattering atmospheres and delicious meals, all while using acoustical impermeable decor.

Noise can also be the result of maximum capacities in restaurants. In Neilson *et al.*'s study [10], the authors discovered noise annoyance correlated with patron density. The study defined patron density as the "patrons per m²" which is considered a strong predictor for speech difficulty, arguing dining establishments should no longer be thought to have "maximum capacity" but rather "acoustical capacity," allowing for dining enjoyment within reasonable noise levels [7, 10]. Other researchers argued for reduced reverberation, also known as "universal design" [7], by making atmospheric adjustments like carpeting, sound absorbent panels, or curtains on the walls and ceilings [2, 7, 9]. While remodeling can be expensive up front, some restaurant owners have found even more success in their business

after acoustics refurbishment. The presence of high levels of noise in an environment devoted to communication, such as restaurants, leads to two effects: the Lombard Effect and the Cocktail Party Effect.

In 1909, Etienne Lombard made the astounding discovery of the changes in voice in the presence of background noise [14]. During patient testing, Lombard observed the patient would raise their voice in the presence of background noise, then return to normal levels when the noise dissipated [15]. This involuntary action of the speaker increasing their vocal effort, while speaking in loud noise, enhancing the audibility of their voice, and later returning to their normal speaking level post-noise is named after the researcher as “the Lombard Effect.” Lazarus stated the speech level corresponds with the noise level, creating a slope of 0.3-0.6 dB per noise level rise of 1 dB for all disturbing noise exceeding 40-50 dB(A) (1986). However, a noise level of 30-40 dB(A) shows minimal effect on an individual’s speech level [16].

In 1953, Cherry [17] presented the findings of the differences in recognition and discrimination of speech. The initial experiment examined an individual’s ability to perceive another speaker’s words while others are conversing at the same time – or known as the “cocktail party problem” [17-18] or the “Cocktail Party Effect” (CPE). The brain’s ability to selectively attend to different speech streams has been assessed by several researchers since then to ascertain how we are able to understand someone in noise. To paraphrase listening in complex environments (such as restaurants) causes an increase in overall brain activity, more specifically the auditory cortex and thalamus. Researchers attribute these cortical areas as due to the individual attempting to attend to auditory cues and ignore the background noise [19]. Golumbic *et al.* [20] reinforced these ideas when examining the role of attention influenced by using low-frequency neuronal oscillations measured by subdural electrocorticography (ECoG) to attend to the signal and ignore the “Cocktail Party” simulation. The study suggested due to the brain’s dynamic activity, it not only uses low-frequency phases, but also high-frequency amplitude fluctuations causing the two to combine [20]. In relation to the auditory cortexes, attention focuses on the primary speech signal modulations and enhances them over time, reducing the attention focused on residual speech occurring – or better explained as “selective attention.”

Recently in 2018, Bottalico began to study the Lombard effect in a restaurant setting [21]. Bottalico identified the Lombard effect in a controlled laboratory setting, using typical restaurant noise. The noise was presented at different levels from 35 dB(A) to 85 dB(A) with 5 dB increments. After reading “The Rainbow Passage” [22], in each noise condition, participants were asked to score their perceived disturbance, how much time they would stay, and how much money they would be willing to spend. The results indicated a change-point of the Lombard effect at 57.3 dB(A), with a slope of the lower segment being 0.31 dB/dB and the upper segment as being 0.54 dB/dB slope. Additionally, this group’s scores for disturbance, time, and money started to decrease at

52.5 dB(A) (disturbance=52.2 dB(A), willingness=51.3 dB(A), money=52.5 dB(A)).

The population analyzed by Bottalico [21] consisted of normal hearing college students aged 18 – 28. This group of people, defined as millennials, “appears to have a higher tolerance for sound” due to their usage of headphones and loud music tastes. Moreover, millennials tend to spend less money in dining out possibly because of their contribution to overall outstanding student loan debt in the United States, which is estimated to be \$1.38 trillion and still climbing [23]. This limits the results of Bottalico [21] to the specific population analyzed.

While millennials are just beginning a new stage of life, the likelihood to be agitated by environmental features is smaller; however, consideration for those who are older, “The Baby Boomers,” is needed. Over several decades, humans have managed to eliminate most infectious diseases through better hygiene, antibiotics, and vaccines which subsequently has increased human life expectancy upwards of thirty years [24-25]. Shen *et al.* [26] quoted that in 2009, 13% of the United States population was 65 years and older, which would eventually increase to 19.3% by 2030. The National Institute on Aging (NIA) states, in their “2020-2025 Strategic Directions for Research,” plan there are approximately 49 million Americans aged 65 and older, which is emphasized to be the largest number of older adults than any other time in history [27]. In recent years, there has been a push for research on understanding the process of aging to better assist these individuals not just in terms of healthcare through prevention, progression, and prognosis [27] – or “healthy aging” – but also in terms of staying connected to society [25].

The American Association of Retired Persons (AARP) memberships permits those aged 50 and older to apply for “full benefits”; therefore, an “older adult” or “senior” can be as young as fifty. It is, however, more common to see individuals who are 60 years and older already contemplating retirement or have fully retired due to the different definitions of retirement in various job fields [28-29]. This population of older adults are more likely to have increased wealth due to pensions, social security, and welfare [30]. While some older adults have chosen to retire, some or most are still actively participating in the world, especially in the dining out experience. However, comorbidities of older adults are high and includes hearing loss.

The World Health Organization estimated forty-six million individuals are distressed by some degree of hearing loss [31]. The National Institute of Deafness and Other Communication Disorders (NIDCD) reinforced hearing loss increases with age and are most commonly found in Caucasian adults aged 60-69 [32]. Goman and Lin [33] stated the most common type of hearing loss in this age group is mild sensorineural hearing loss. For older adults, independent of hearing status, restaurants are one of the primary environments noted to have increased difficulty [1, 18, 34]. As many as 52% of individuals are disturbed and 88% have problems conversing [7]. It has been proven, as we age, older adults have reduced, bilateral auditory region activity, in conjunction with increased frontal and posterior parietal lobe activity.

These alterations create a broader processing ability causing a subconscious compensatory strategy to speech-in-noise situations [35]. The broad networking can lead to increased listening effort causing fatigue [7, 18]. However, untreated hearing loss in older adults not only causes auditory deprivation and increased listening efforts, but the potential for cognitive decline and decrease overall quality of life [36].

Additionally, there is the phenomenon of older adults having correctly heard information presented, but it is misperceived (even with context); and to reduce embarrassment, older adults will not ask for repetition [37], contributing to the stress of dining out. This event is caused by the deficit of seniors' reliance on linguistic knowledge to counteract reduced processing speeds for speech-in-noise environments [37]. Since high frequency hearing loss is most common, there is some variance in responses by older adults in speech-in-noise situations [38], which could be explained by the reverberation of the restaurant setting [9]. With older adults, it is critical to be actively participating in providing them with the best signal-to-noise ratio (SNR) as possible, with or without the assistance from hearing devices, in order to create hearing- and age-friendly environments, like restaurants, to reduce the risk of isolation and depression due to the lack of the ability to socialize [39].

Heinrich *et al.* [40] found speech perception correlated with hearing sensitivity levels, even when hearing loss was ruled out. As part of the auditory assessment battery, it is typical for patients to receive a speech intelligibility test. The purpose of an intelligibility test not only assists in confirmation of the hearing loss, but also helps the audiologist to understand where the patient is having deficits in real-world conversations [41]. There are various reasons as to why speech intelligibility in the presence of noise is problematic. Primarily the most significant reason is the fundamental frequency of the voice per gender, which is lower for males versus females [42]. However, Bronkhorst [42] continued to note the environment, distance from the primary talker, distance from other conflicting talkers varies greatly on intelligibility. The study reinforced even with changeable qualities, the comorbidities of limited vocal output and poor pronunciation by a speaker or the possibility of hearing loss, contributed to deficits in speech intelligibility [42]. New studies to evaluate vocal reliability in older adults have become more critical; and adults over the age of 65 have been reported to have a 25% chance of developing a voice disorder [43]. With the combination of vocal fatigue, hearing loss, and maximum seating occupancy in restaurants, it is imperative to assess the level of noise older adults begin to experience less than 50% intelligibility.

Therefore, there is a glaring need to consider the senior population and their needs regarding dining out, with the aim of creating more age-friendly communities.

With the goal of understanding how the senior population will react to noise in a restaurant setting, in terms of voice production (the Lombard Effect) and speech perception (the Cocktail Party Effect), the following research will investigate five different outcomes. In this study, thirty-one participants, aged 60 and older, were asked to read a

passage in the presence of eleven randomized noise conditions ranging 35 dB(A) to 85 dB(A). After each passage reading, an intelligibility test was performed, and a visual analog scale was handed to the participant to rate their amount of disturbance and willingness to spend time and money in a restaurant. The aim of this study will attempt to answer the following research questions:

- 1) What is the level of noise at which older adults experience the Lombard effect?
- 2) What are older adults' amount of disturbance perceived in each of the eleven noise conditions?
- 3) How much time they would be willing to stay in the environment?
- 4) How much money they would be willing to spend in the same environment?
- 5) What is the noise level at which older adults are no longer able to have an intelligible conversation?

2. METHODS

2.1 Participants

A total of 42 individuals were recruited for the study (females = 24, males = 18). Inclusion criteria required the participant to be over the age of sixty years and have normal hearing (<25 dB HL) or hearing loss (> 25 dB HL); additionally, participants must be proficient English speakers, since the intelligibility test will be given in English. Exclusion criteria included those under the age of sixty, not a native English speaker, and an air-bone gap greater than 15 dB HL without a previous medical consultation with an otolaryngologist (ENT). The participants signed a consent form, completed a demographics form, and underwent a hearing test prior to completion of the experiment. The hearing test included otoscopy, tympanometry, speech reception thresholds, and air and bone conduction audiometry. This resulted in thirty-one participants; the final participant demographics are recorded in Table I.

Demographic	Normal Hearing	Mild HL	Moderate – Severe HL
Male	2	4	8
Female	8	6	3
Caucasian	10	10	11
English speaker	10	10	11
Smoker	0	0	0
Acid Reflux	5	2	2
Asthma	2	0	0
Allergies	4	5	7
Lung-Heart Disease	3	0	3
Speech Therapy	0	0	1
Voice Training	2	1	2

Table 1. The demographics of the final 31 participants separated by hearing loss category.

2.2 Procedure

After participants confirmed their age, they were scheduled to participate in the study. Prior to completing the hearing test, participants reviewed their hearing

history with the graduate student. Afterwards, otoscopy and tympanometry at 226 Hz were performed to rule out a conductive pathology (primarily cerumen or middle ear fluid).

After completion of the hearing test, the individual continued with the Lombard Effect testing, speech-in-noise intelligibility testing, and scored on a visual analogue scale their perceptual responses of (1) communication disturbance, (2) willingness to spend time, and (3) willingness to spend money in a restaurant. Participants completed all components of the study in one or two forty-five to sixty-minute sessions, resulting from scheduling conflicts and/or participant fatigue.

2.3 Hearing loss categorization

After the hearing evaluation, participants were grouped in three categories. These categories were determined by the collective pure-tone averages of 2000 Hz, 4000 Hz, and 8000 Hz of both ears per participant. The calculated high frequency average was classified into: 1) normal hearing [<25 dB HL], 2) mild sensorineural hearing loss [26-40 dB HL], 3) moderate, severe, & profound sensorineural hearing loss [41+ dB HL]. All categorization was based on ASHA [44] and Clark [45] degrees of hearing loss.

2.4 Measuring the Lombard Effect

Participants were fit with the head-mounted microphone connected to a portable recorder. Then, participants were asked to read in the presence artificial restaurant noise the first six sentences of “The Rainbow Passage” [22], which is used by Speech Language Pathologists to assess and monitor voice and articulation disorders. The synthesized noise was presented in a random order at eleven levels from 35 dB(A) to 85 dB(A) with 5 dB interval. The speech was recorded with the software Audacity 2.0.6 (SourceForge, La Jolla, CA). Participants were instructed, by the undergraduate student assistant, with the following: “Each time, I [the listener] would like you to pretend that we are talking in a restaurant and you are telling the story to me. Make sure that I understand you equally well each time.”

2.5 Measuring Speech Intelligibility in Noise

The participants completed a speech-in-noise intelligibility test for each of the eleven, randomized noise conditions. Our intelligibility test was designed using the 250-300 standardized Northwestern University #6 [46] words available to all audiologists. These words were recorded using the voice of an undergraduate student assistant; the words were individually clipped and then randomized into eleven, twenty-word lists. These recordings were then played through a Head and Torso Simulator (HATS)(GRAS, Holte, Denmark), placed at one meter distance from the participant, to eliminate participants' reliance on visual cues to lip-read. The word lists were presented at a level of 66 dB(A), corresponding to a raised vocal effort at one meter of distance [47].

Participants were asked to repeat the word pronounced by the HATS. Intelligibility scores were measured as percentage of words correct.

2.6 Recording Disturbance, Time, & Budget Scores

Self-reported communication disturbance and willingness to spend time and money were measured on visual analog scales on paper. The participant was instructed to place a vertical tick on the horizontal line regarding their amount of disturbance, time, and money per noise condition. The paper document was then scanned and uploaded to be measured, in centimeters, using Adobe Acrobat Pro DC Software and the Adobe Software Measurement Tool. The responses were then recorded in an Excel spreadsheet according to the participant's identification number.

2.7 Analysis of Voice Recordings

The audio recordings of participants were pulled from an SD card and segmented using ELAN software (v5.8). Each of the eleven “Rainbow Passage” segments were saved according to the participants identification number and noise level condition. MATLAB (R2017a) was used for speech signal analysis. In each condition, the equivalent SPL was measured. For each condition, the mean value of the SPL was obtained per subject. For each subject, the average of SPL among the conditions was computed and subtracted from each mean SPL values for that subject (termed Δ SPL). This within-subject centering was performed in order to evaluate the variation in the subject's vocal behavior in the different noise conditions from their typical vocal behavior (mean value of the SPL per subject). Each participant was identified by their identification number, gender, age and type of hearing loss.

2.8 Equipment & Room Measurements

The study was performed in a sound-attenuated booth. Reverberation time was measured in the sound booth from the impulse responses (IRs) generated by balloon pops [47]. The four IRs were recorded in two source positions and two microphone positions by means of an NTI Measurements microphone M2211 (Class 1 frequency response) and analyzed in one-third octave bands by means of an NTI XL2 Audio and Acoustic Analyzer. The reverberation time (T20) at mid-frequencies in the room was 0.05 s, while the background noise was 22.5 dB(A). The hearing test will be performed using a calibrated tympanometer (TymStar, Grason-Stadler, Eden Prairie, MN), audiometer (GSI 61, Grason-Stadler, Eden Prairie, MN), insert phones (3M E-A-RTONE 5A 410-5002, 50 Ω), TDH-50 headphones, and bone oscillator. The participants' speech will be recorded using a head-mounted microphone (Beta 54 WBH54, Shure, Niles, IL) and connected to an audio interface (US-, TASCAM [DR44], Montebello, CA). Synthetic restaurant noise was emitted by two directional speakers

(High performance 100 dB speaker, E3 Diagnostics, Arlington Heights, IL) placed at 45° to the sides of the participants using the same stimuli.

3. RESULTS

The Δ SPL was measured at each of the 11 noise levels between 35 and 85 dB(A), as shown in Figure 1. A piecewise linear model was fit to the response variable, Δ SPL, and the predictor, Ln. The presence of Hearing Loss (HL) did not statistically influence the Lombard Effect. The piecewise linear model individuates a breakpoint in Ln at 58.3 dB(A) (CI 95% lower: 53.4, CI % upper: 63.3). The slope of the lower segment was 0.27, and the upper was 0.51, with an R-squared of 0.86.

Figure 1. Δ SPL per each of the 11 noise conditions.

Self-reported communication disturbance was measured at each of the 11 noise levels (Figure 2). A piecewise linear model was fit to the response variable, disturbance (% of “very high”) and the predictors, Ln and HL. The piecewise linear model individuates two breakpoints, the first at 51.6 dB(A) (CI 95% lower: 41.4, CI % upper: 60.3) and the second at 66.9 dB(A) (CI 95% lower: 62.0, CI % upper: 71.2). The slope of the lower segment was 1.77 percent-points per dB (pp/dB), the medium was 2.78 (pp/dBA) and the upper was 0.83 (pp/dBA). In in the same noise level condition, compared to participants with normal hearing, participants with mild HL scored the disturbance 9.37% higher, while participants with moderate to severe HL scored the disturbance 5.87% higher. The R-squared of the model was 0.78.

The willingness to spend time in the restaurant was measured at each of the 11 noise levels, as shown in Figure 3. A piecewise linear model was fit to the response variable, time willing to stay (% of “A long time”) and the predictors, Ln and HL. The piecewise linear model individuates a breakpoint in Ln at 65.8 dB(A) (CI 95% lower: 58.9, CI % upper: 72.7). The slope of the lower segment was -2.27 (pp/dBA), and the upper was -1.00 (pp/dBA). In in the same noise level condition, compared to participants with normal hearing, participants with mild HL scored the time willing to stay 6.62% lower, while participants with moderate to severe HL scored the

disturbance 4.79% lower. The R-squared of the model was 0.73.

Figure 2. Amount of disturbance perceived in each noise condition.

Figure 3. Amount of time willing to spend in each noise condition.

The willingness to spend money in the restaurant was measured at each of the 11 noise levels, as shown in Figure 4. A piecewise linear model was fit to the response variable, money willing to spend (% of “All the budget”) and the predictors, Ln and HL. The piecewise linear model individuates two breakpoints, the first at 54.6 dB(A) (CI 95% lower: 40.9, CI % upper: 60.0) and the second at 61.99 dB(A) (CI 95% lower: 57.98, CI % upper: 65.99). The slope of the lower segment was -1.80 percent-points per dB (pp/dB), the medium was -3.86 (pp/dBA) and the upper was -0.87 (pp/dBA). In in the same noise level condition, compared to participants with normal hearing, participants with mild HL scored the time willing to stay 12.06% lower, while participants with moderate to severe HL scored the disturbance 8.11% lower.

The intelligibility in the restaurant was measured at each of the 11 noise levels, as shown in Figure 5. A piecewise linear model was fit to the response variable, intelligibility scores (% of correct word recognized) and as predictors, Ln, HL and their interaction. The piecewise linear model individuates two breakpoints, the first at 51.2 dB(A) (CI 95% lower: 48.2, CI % upper: 54.2) and

the second at 71.3 dB(A) (CI 95% lower: 68.4, CI % upper: 74.2). Because of the interaction between Ln and HL, in each of the three segment there is a slope for each HL levels (Normal, Mild and Moderate-Severe). The slopes of the lower segments were -1.08, -0.98, and -0.32 percent-points per dB (pp/dB) for participants with Normal Hearing, Mild HL and Moderate-Severe HL, respectively. The slopes of the medium segments for the three groups were -3.39, -3.30, and -2.64 percent-points per dB (pp/dB), while the slopes of the upper segments for the three groups were -0.65, -0.56, and 0.10 percent-points per dB (pp/dB). The R-squared of the model was 0.85.

Figure 4. Amount of budget willing to spend in each noise condition.

Figure 5. Intelligibility percentages by noise condition.

4. CONCLUSION

The goal of this study was to identify the starting point of Lombard Effect in older adults which occurred at 58.3 dB(A), as well as the slope of the Lombard Effect which was identified at the lower segment as 0.27 and the upper segment as 0.51. As the noise increased, so did older adults' amount of perceived disturbance, beginning at 51.6 dB(A) and a second beginning saturation levels at 66.9 dB(A), as well as decreased willingness to spend time, starting saturation levels at 65.8 dB(A), and money, starting at 54.6 dB(A) and reaching saturation by 62.0 dB(A) in the synthesized restaurant setting. Additionally,

at one meter's distance with one talker, intelligibility results reflected that moderate-to-severe hearing loss participants already were at approximately 50% correct word understanding in the lowest noise level condition even when they were unaided. By 70 dB(A) all hearing categories (normal, mild, and moderate-to-severe) were almost or at 0% correct words. This is a problem as many restaurants can exceed this threshold by 15 dB or more in real-world environments causing many patrons to be unable to have an effective communication when they go out to dine. The results showed that a background noise level lower than 50 dB(A) will allow the senior customers to minimize their vocal effort and to understand more than 50 % of the conversation even for people with moderate to severe hearing loss. The same limit will also keep the disturbance of the communication below the 50% and the willingness to spend time a money in a restaurant above the 50%.

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