DOI: 10.61782/fa.2025.0784

FORUM ACUSTICUM EURONOISE 2025

SOUND DESIGN IN BEAUTY TECH: IMPROVING THE SOUNDS OF HAIR DRYERS

Anjali Bhatara[1,2*] **Aldina Suwanto**[2] **Sébastien Romagny**[2] **David Morizet**[2]
[1] Ircam Amplify, Paris, France
[2] L'Oréal Research & Innovation, Clichy, France

ABSTRACT

Sound can strongly affect users' emotions and perceptions of a product, but it is often neglected in traditional sensory research. In the present study, we investigate a beauty tech product that makes sound as a consequence of its function: hair dryers. We recorded the hair dryers' sounds and digitally modified the spectral content of the recordings. We then tested these recordings and modified versions with a group of consumers to evaluate the effect of the modifications on listeners' preferences and the emotional impact of each sound. We find clear positive effects of spectral modifications on both preference and emotion. Specifically, increasing sharpness (by increasing high-frequency energy) and reducing energy in the high-mid frequencies results in higher preference and more positive emotions. These results demonstrate the importance of carefully designing sounds in beauty tech, even those that are unintentionally part of the user experience, and they also demonstrate an original and cost-effective method for evaluating potential improvements to a product's sound.

Keywords: *sound design, beauty tech, emotion, user experience*

**Corresponding author*: david.morizet@loreal.com

1. INTRODUCTION

The sound a product makes may not be the first thing people consciously notice about it. It is likely that they first look at it; then they may touch it, smell it, feel its weight. But the sound it makes, though sometimes only unconsciously noticed, communicates information about its characteristics and qualities and can have strong effects on its emotional impact see [1] for an in-depth discussion. This effect is product specific. Blauert & Jekosch [2, p. 747] define sound quality as the "adequacy of a sound in the context of a specific technical goal and/or task." This means that there is no universal auditory characteristic that a good product sound should have. The quality and appropriateness of a sound are interdependent.

Products' sounds can be broadly divided into two categories: intentionally created sounds (e.g. user interface sounds) and sounds that are a consequence of the product's use (e.g., motor sounds). These sounds that were not intentionally created can, however, be made intentional. The "click" sound of lipstick being closed after use, for example, depends on the material and configuration of the lipstick tube, and it can influence users' perceptions of the lipstick's characteristics [3].

In the present study, we examine an unintentional sound: the motor + air sound of a hair dryer. These sounds can be characterized as "noise" and exemplify one of the challenges of sound design – making the best of a sound which is a side effect of an object's material, structure, or function [4]. We chose to examine this device because it makes sustained, relatively loud noise which occurs close to the ear of the person whose hair is being cared for, and therefore it is likely to have an impact on the multisensory experience of visiting a hair salon or of drying one's hair at home.

A few acoustic parameters are often evaluated when testing product sound. Many of these have to do with the spectral content, that is, the distribution of different frequencies in the sound and their relative energy. Others have to do with changes in the sound over time. In the following section are basic definitions of a few of these acoustic parameters.

Pitch is how high or low we perceive a sound to be. Pitch often depends on the placement of the fundamental frequency [5]. ***Tonality*** is defined in a study on hair dryer noise [6] as how perceptible specific pitches are within a noise. A white noise, like those often made by machines designed to block out other noise to help us sleep, has no tonality. The energy across all the frequencies is equal, so none are individually audible. The measure we will use in the present paper will serve as the inverse of this, though it is more specific: ***spectral flatness*** [7]**.** This is a measure of how close a sound is to white noise, and it is also sometimes called the "tonality coefficient" [8]. A sound with individual tones or narrow bands that are audible would have low spectral flatness. Other colors of noise, such as brown or pink noise, even without tonality, would also be lower in spectral flatness than a white noise. ***Spectral centroid*** is one way of describing the power spectrum of a sound; it is the spectral center of gravity of a sound and is measured in Hertz (Hz) like the fundamental frequency e.g., [9]. The higher this frequency is, the brighter the sound. ***Sharpness*** is related to brightness; it depends on the relative amount of high-frequency energy in the sound. More high-frequency energy leads to higher sharpness, which in turn is correlated with decreasing sensory pleasantness. [10].

Changes in the sound over time can include fluctuations in pitch or in amplitude (loudness). Sounds with fast fluctuations in amplitude are often described as ***rough***, and slower fluctuations are perceived more as beats, measured as ***fluctuation strength*** [10]. Sounds with high roughness are generally regarded as less pleasant than non-rough sounds [10], [11].

Consumer preference has been evaluated in several types of noise-creating products. More annoyance or reduced preference was found to be caused by more pitch fluctuation in refrigerators [12], larger pitch variations and higher pitch [13] or higher tonality and spectral centroid [14] in air conditioners, higher sharpness, tonality, and fluctuation strength in helicopter noise [15], high tonality in hair dryers [6] and higher sharpness in coffee machines [16] and electric toothbrushes [17].

For the present study, we analyzed the sounds of four different hair dryers. In addition, we digitally modified the sound of one hair dryer (Hair dryer D) to increase or reduce its sharpness, spectral flatness, roughness, and other aspects of the frequency distribution, such as relative energy in low, mid, and high frequencies. We then presented these sounds to consumers and asked them to rate the sounds on emotion, using a timed task to evaluate their initial reactions, and we measured their preference using a Best-Worst Scaling task [18]. We chose this method because it was shown to be as effect as rating scales, but preferred by participants [19]. We then explored the relation between these preference and emotional ratings and the sound manipulations.

Because previous studies have shown that loudness level (sound pressure level, SPL) is a major factor in determining hair dryer discomfort [6], noisiness of refrigerators [12], as well as preference for air conditioners [14], electric toothbrushes [17], and coffee machines [16], for the present study we normalized the sounds to have the same SPL. This way, we can more easily examine other aspects of the sound spectrum that determine preference.

Based on previous evidence, we predicted that higher sharpness, lower spectral flatness (i.e., higher tonality), and higher roughness would all be negatively related to preferences and positive emotions.

2. METHODS

2.1 Participants

Thirty-nine French-speaking women were tested at in the L'Oréal Cognitive Sciences lab in Clichy, France (M_{age} = 43 y, range 23-60). Inclusion criteria were being 60 years of age or younger, reporting no hearing loss, and regularly using a hair dryer. All participants' personal information was handled following the GDPR, and the study followed the guidelines of the Declaration of Helsinki. All participants signed an informed consent document before beginning the study, and they were compensated for their time.

2.2 Stimuli

2.2.1 Recordings

The hair dryers selected consisted of four high-end hair dryers. One of the hair dryers, Hair Dryer D, was further explored by digitally modifying recordings of its sound. The recordings were done in the Cognitive Science lab in a semi-anechoic room. Four hair dryers were measured in three different configurations, placing the microphone (MiniDSP UMIK-1) in different places relative to the air flow (see Fig. 1). Configuration 1 had the microphone placed 30 cm behind the hair dryer. Configuration 2 had the microphone placed 10 cm away from the end of the hair dryer where the air exited, perpendicular to the hair dryer and in the same horizontal axis (parallel to the floor). Configuration 3 was like 2, but the hair dryer was pointed at the mannequin head. Our goal was to investigate the sound experienced by the person whose hair is being dried. Configuration 2 was chosen because it measured the sound in front of the hair dryer without too much of the air flow (directly from the hair dryer or bouncing off the head) interfering with the sound. The hair dryers were at their maximum setting (speed and temperature) and without any styling attachment.

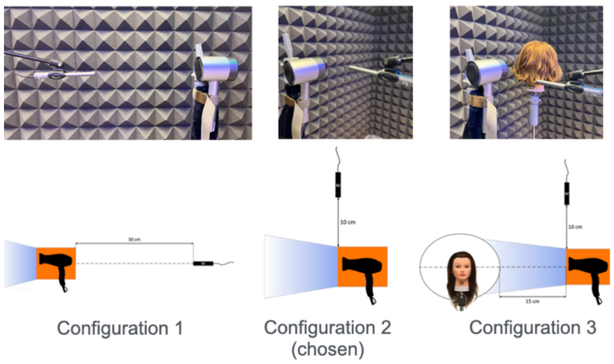

Figure 1. The three configurations of hair dryer and microphone for the recordings

2.2.2 Sound treatment and modifications

Recordings were normalized at -24 LUFS. Stimuli consisted of the four original recordings of hair dryer sounds and 17 digitally modified versions of Hair Dryer D. These modifications were performed using the software Reaper, equalized with ReaEQ and are outlined in Table 1.

The specific modifications were chosen based on previous studies and predictions (i.e., modification of sharpness which has been shown to be unpleasant in other contexts, boosts in different areas of the spectrum to examine the effect of concentrated high vs low frequency energy) and examination of the hair dryer signal (the resonance modifications, which involved boosting or cutting in existing frequency peaks).

Table 1. Details of stimulus modifications

Type of modification	Q	Frequencies altered	Intensity change	# of sounds
Sharpness: High shelf	1.5	1500 Hz; 5 kHz;	±10 dB	4
Resonance: Bell boost and cut of two peaks	0.5	1600 Hz; 5000 Hz	±10 dB	2
Wide frequency cut	4	1500; 3000; and 6000 Hz	±20 dB	3
Narrow frequency cut	2	1500 Hz; 3000 Hz; 12 kHz, Q=2	0 & -10 dB	3
Narrow frequency boost	2	375; 750; 1500; 3000; 6000 Hz, Q=2	+20 dB	5

2.3 Procedure

Participants were tested in a dedicated testing booth. Sounds were presented through Beyerdynamics DT770 Pro 32Ω headphones. The volume setting on the computer was consistent across participants. Participants were told that they would be hearing hair dryer sounds and that they would be asked for their opinions on them.

The experiment consisted of two parts. In the first part, participants heard the sounds presented in random order, and for each sound they were asked to respond to a list of emotions whether the sound made them feel that emotion. They heard the sound and then saw the list of emotions one at a time. The order of presentation for the emotions was randomized for each participant, and it stayed consistent within the participant (that is, for each sound, the emotions were presented in random order A for participant 1, random order B for participant 2, etc.). As each emotion was presented, participants had 1500 ms to say “Yes” or “No” by pressing a corresponding key on the keyboard. If their response was too slow, it was not recorded. This method was chosen to try to get at more spontaneous “gut” reactions without allowing the participant time for conscious thought about whether they felt the emotion or not.

The second part was a Best-Worst Scaling task: participants heard the sounds presented in 21 groups of five using a balanced incomplete block design created using the R Commander plugin for the support.BWS package in R [20], [21], [22]. They were asked to choose the best and the worst sound among the five. They had to listen to each sound at least once before they could respond, and they could replay the sounds as many times as they wanted.

2.4 Statistical Analysis

Emotion results were analyzed using the MultiResponseR package in R [23]. Data were first cleaned so the only "yes" responses to emotions were those that were given between 300 and 1500 ms after the sound was heard, with the reasoning that responses shorter than 300 ms were too fast and unlikely to be genuinely in response to the sound. All others were classified as "no" responses.

Best-Worst scaling data were analyzed using the support.BWS and survival packages in R [20], [22], [24], [25]. A conditional logistic regression with a MaxDiff model was run using the clogit function, giving the odds ratios with 95% confidence intervals for each of the stimuli. We chose the narrow boost at 375 Hz as the reference level because it was one of the worst rated, and we had sufficient narrow boosts at other frequencies to see trends relating ratings to these boosts at specific frequencies.

To examine the effect of sharpness, roughness, and spectral flatness on best-worst scaling results, we performed Pearson product-moment correlations among these three measures and the best-worst score (number of times chosen as best minus number of times chosen as worst) using base R and corrplot packages [26], [27].

3. RESULTS

For the emotions, a multiple-response chi-square test showed that the responses were distributed differently from expected, $\chi^2(460) = 533.79$, $p < .001$. A within-subjects test of dimensionality showed only one dimension was significant at $p < .001$. A correspondence analysis was performed and shows the first two dimensions (Fig. 2). The x axis indicates an effect of valence, with positive on the left and negative on the right. The non-significant y axis suggests an effect of arousal, but this is less clear than the valence effect.

The within-subjects multi-response hypergeometric test showed numerous hair dryer sounds that were rated significantly differently from expected. Narrow and Wide cuts at 1500 and 3000 Hz, added Sharpness above 5000 Hz, and Resonance reduced at 1600 Hz were rated

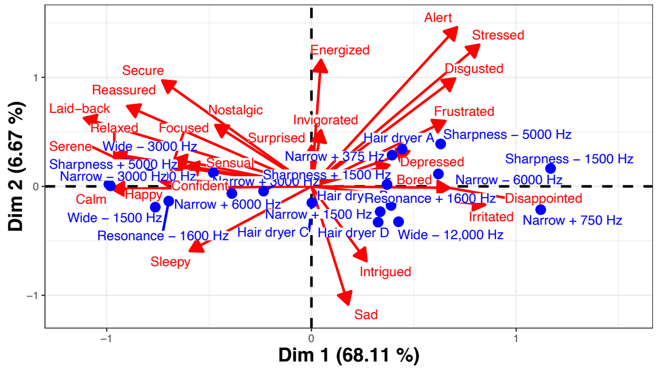

Figure 2. Correspondence analysis of the emotion ratings of the hair dryer sound

similarly: many were rated less alert, and they received more yeses for low-arousal positive emotions such as laid-back, relaxed, serene, sleepy, reassured, and calm. Some of them were also less irritated and/or stressed. In contrast, Sharpness reduced above 1500 Hz and Narrow boost at 750 Hz were more irritated, alert, and stressed and were rated lower on the low-arousal positive emotions. There were no significant differences in bored, confident, depressed, disappointed, disgusted, energized, frustrated, intrigued, invigorated, nostalgic, sad, or surprised. The significant differences are shown in Fig. 3. Sounds with no significant differences in emotions are not shown in the table.

A forest plot of odds ratios resulting from the best-worst scaling conditional logistic regression is shown in Fig. 4. The hair dryers with confidence intervals that do not overlap the dotted line were significantly rated as best (if above the line) or worst (if below the line).

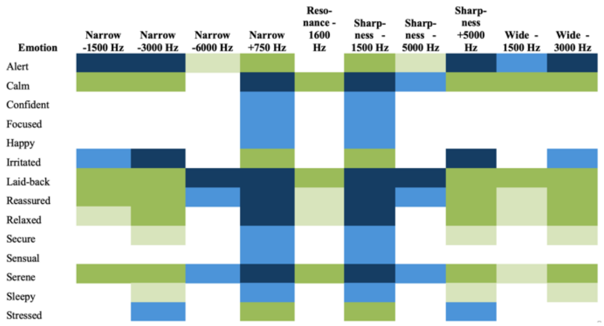

Figure 3. Results of the hypergeometric test for the hair dryer sounds. Cells that differed significantly from expected are highlighted. Green means more than expected, and blue means less than expected. Darker colors are significant at $p < .05$, and lighter colors approach significance at $p < .1$

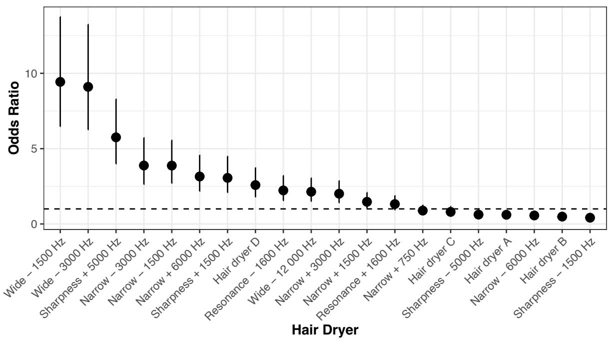

Figure 4. Odds ratios for Best-Worst scaling of the hair dryer sounds. The dotted line indicates an odds ratio of 1, that is, neither best nor worst. Error bars are 95% confidence intervals.

Eleven of the hair dryer sounds were rated more often as best: Wide cuts at 1500, 3000, and 12,000 Hz, Narrow cuts at 1500 and 3000 Hz, a Narrow (resonance) cut at 1600 Hz, boosted sharpness above 5000 Hz and above 1500 Hz, the Narrow boost at 6000 Hz, and the unmodified Hair Dryer D.

A correlation analysis among best-worst score, sharpness, spectral flatness and roughness showed that best-worst score was significantly positively correlated with sharpness, $r(19) = .70$, $p < .001$, and negatively correlated with roughness, $r(19) = -.68$, $p < .001$. The correlation with spectral flatness was not significant, $r(19) = .33$, $p > .05$. As can be seen in the scatterplot, an

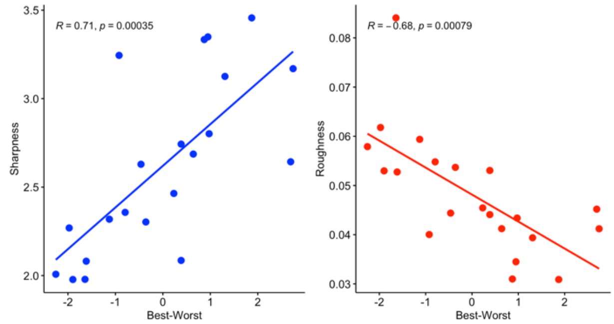

Figure 5. (Left) Scatterplot showing the positive correlation between Best-Worst and sharpness (Right) Scatterplot showing the negative correlation between Best-Worst and roughness.

outlier analysis shows that one of the sounds (the dot next to the correlation coefficient in the plot) was an outlier for roughness. Removing this outlier increases the negative correlation to $r(19) = .71$, $p < .001$.

4. DISCUSSION

The results of this experiment have shown that 1) variations in the acoustic characteristics of the natural sounds made by hair dryers can affect users' emotions, and 2) users have clear preferences for certain types of sounds over others. We have also demonstrated an effective testing methodology for examining preferences and emotions in these types of product sounds, combining techniques from psychoacoustics and sensory science. Regarding our initial hypotheses, neither sharpness nor tonality had negative effects on ratings for either object, but roughness did.

Though tonality did not have a significant impact, there was a positive effect of sharpness, including a positive correlation between sharpness and best-worst score, combined with a strong effect of reduction in the high-mid frequencies. The top six most preferred sounds had either reductions at these high-mids or added sharpness in the high frequencies. Many of these, especially those that reduced the high-mids were also rated with more positive and fewer negative emotions than expected. In contrast, the sounds rated as worst had reduced sharpness and tended to receive more "yes" responses for negative or high arousal emotions and fewer for positive and low arousal emotions.

The preference for reductions in the high-mid frequencies may be due to the fact that human ears are most sensitive to frequencies in this range – our threshold for hearing in quiet is lowest between 2 and 5 kHz [10]. A reduction of frequencies in this range may give an illusion of overall sound level reduction, and lower sound level is generally preferred in sounds such as these [6], [14], [17].

Roughness was also found to be negatively correlated with best-worst ratings. This is in line with previous work suggesting negative impacts of roughness on preferences. However, the preference for increased sharpness was opposite of what we had predicted based on previous research. This result can be taken as a demonstration of how context- dependent sound preferences are. Studies on coffee machine noise [16] and car engines [28] showed a preference for reduced sharpness, which is what led us to the initial prediction.

Higher sharpness means more energy concentrated in higher frequencies, which in turn means less energy in lower frequencies. Pitch, the perception of high or low tones, is related to size perception [29], [30], perhaps because large animals and objects make low sounds and smaller animals and objects make higher sounds. We can speculate that a concentration of more energy in lower frequencies may give an impression of greater size or power, which is more desired in coffee machines or car engines. Relatively more high-frequency energy may lead to a perception of a smaller, less powerful or less imposing object, and being smaller and less powerful may be preferred in hair dryers.

It is possible that there is individual variation not captured by the experimental manipulation. In the study by Susini et al. [14] on air conditioner noise, the authors found that participants could be separated into two groups by which aspects of the sound determined their preferences. It could also be interesting to further explore across cultures. Our sample consisted mainly of French women; non-Western participants or men (who on average have shorter hair and hence less experience with hair dryers) may react differently to the sounds. It could also be interesting to explore other sounds present in beauty and pampering contexts to see if they follow similar trends regarding preferences.

5. CONCLUSION

The results of this study show that the organic or unintentional sound made by Beauty Tech devices is an important but underexplored area of research. One of the main reasons it is important is sustainability: all tech used in beauty and any device intended to be more sustainable must be carefully designed for long-term, regular use, in sharp contrast with more "gimmicky" devices that are often used for only a short time and then thrown away. This means paying attention to all aspects of the sensory experience, including both designed and byproduct sounds. Engineers and designers in these domains can take inspiration from Active Sound Design in the automotive industry e.g., [31], where the existing sound of the road and engine are altered to be more appealing. Specific to reaching this goal with hair dryers, the present study showed that small alterations of the frequency spectrum can increase both positive emotions and preference for their sounds. This study also demonstrates effective techniques for an original and cost-effective way to explore potential improvements to a device's sound with a panel of consumers. The results of this study can inform subsequent stages of design as well as design of future sustainable beauty products.

6. ACKNOWLEDGMENTS

We thank Pablo Martin for recording and analysis of the original recordings, and Pierrick Pedron and Romain Barthelemy for normalizing and modifying the sound files.

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