



Audio Engineering Society

# Convention Paper 10175

Presented at the 146<sup>th</sup> Convention  
2019 March 20 – 23, Dublin, Ireland

*This paper was peer-reviewed as a complete manuscript for presentation at this convention. This paper is available in the AES E-Library (<http://www.aes.org/e-lib>) all rights reserved. Reproduction of this paper, or any portion thereof, is not permitted without direct permission from the Journal of the Audio Engineering Society.*

## Background Ducking to Produce Esthetically Pleasing Audio for TV with Clear Speech

Matteo Torcoli<sup>1</sup>, Alex Freke-Morin<sup>1,2</sup>, Jouni Paulus<sup>1,3</sup>, Christian Simon<sup>1</sup>, and Ben Shirley<sup>2</sup>

<sup>1</sup>Fraunhofer Institute for Integrated Circuits IIS, Erlangen, Germany

<sup>2</sup>Acoustics Research Centre, University of Salford, UK

<sup>3</sup>International Audio Laboratories Erlangen, a joint institution of Universität Erlangen-Nürnberg and Fraunhofer IIS

Correspondence should be addressed to Matteo Torcoli ([matteo.torcoli@iis.fraunhofer.de](mailto:matteo.torcoli@iis.fraunhofer.de))

### ABSTRACT

In audio production, background ducking facilitates speech intelligibility, while keeping the background track enjoyable. Technical details for recommendable ducking practices are not currently documented in literature. Hence, we first analyze common practices found in TV documentaries. Second, a subjective test investigates the preferences of 22 normal-hearing listeners on the Loudness Difference (LD) between commentary and background during ducking. Highly personal preferences are observed, highlighting the importance of object-based personalization. Statistically significant difference is found between non-expert and expert listeners. On average, non-experts prefer LDs that are 4 LU higher than the ones preferred by experts. Based on the test results, we recommend at least 10 LU difference between commentary and music and at least 15 LU between commentary and ambience.

### 1 Introduction

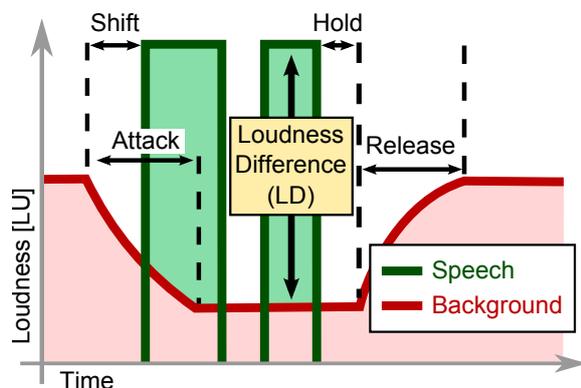
One of the most common complaints to broadcasters is about the low intelligibility of the foreground speech (e.g. dialog and commentary) in TV programs due to the background (sometimes also referred to as *bed*) being too loud compared to the speech [1]. The background includes music and effects that are essential for the full understanding and enjoyment of the show. However, the background can energetically mask the speech, making it impossible or tiring to understand. In some cases, the background also includes background speech, e.g. Voice-over-Voice (VoV), where a foreground voice translates a foreign language in the background. In this case informational masking can also occur [2].

Audio producers are challenged with the task of producing audio mixes with enjoyable background and fully

intelligible foreground speech, at least under favorable listening conditions. In order to do so, it is common practice to attenuate the level of the background during periods of activity of the foreground speech.

This can be executed in different ways, which are all referred to as *ducking* in this paper. The most common ways are manual volume automation in a digital audio workstation and the side-chain compression of the background triggered by the foreground speech signal<sup>1</sup>. A combination of manual and side-chain control can also be used. In every case, a number of parameters are involved that need to be tuned.

<sup>1</sup>The technique based on the side-chain compression is what many audio engineers refer to as *ducking*. This paper uses the term *ducking* with a broader meaning, referring to any time-varying background attenuation with the aim of making the foreground speech clear.



**Fig. 1:** Ducking the background while foreground speech is active. This is controlled by parameters such as the Loudness Difference (LD) between speech and background during ducking and time constants (attack, shift, hold, release).

These parameters are shown in Fig. 1 and can be categorized into 2 groups: time constants and level parameters. The time constants can be described by typical compressor parameters such as attack and release, complemented by a shift time, which describes the attack offset before speech is starting, and a hold time, which prevents *pumping* in short speech gaps. The main relative level parameter is the Loudness Difference (LD) between foreground speech and background.

As loudness measure we adopt the integrated loudness as per ITU BS.1770-4 [3], i.e. as per EBU R 128 [4]. This is measured in Loudness Units Full Scale (LUFS) if relative to digital full scale or in Loudness Units (LU) if related to another specified level, e.g. in the case of the LD. A handy property of the LU is that a level increase by 1 dB leads to a 1 LU increase.

Best practices for an esthetically well tuned ducking are not defined by mixing handbooks and broadcaster recommendations. Often the only recommendation given is that foreground speech has to be “comprehensible” and “clear”.

This paper sheds some light on the ducking parameters by studying the LD. This is done by analyzing the practices found in a sample of TV documentaries and by carrying out a subjective test on the LDs preferred by normal-hearing listeners. Related works are also reviewed and compared with our findings.

## 2 Literature Review

### 2.1 The perfect TV audio mix is personal

The right balance between foreground speech and background was shown to depend on personal taste [5, 6], listener’s hearing acuity [7, 8, 9, 10], listening environment (e.g. environmental noise [11]), reproduction system (e.g. [12]), and listener’s mother tongue and content language [13].

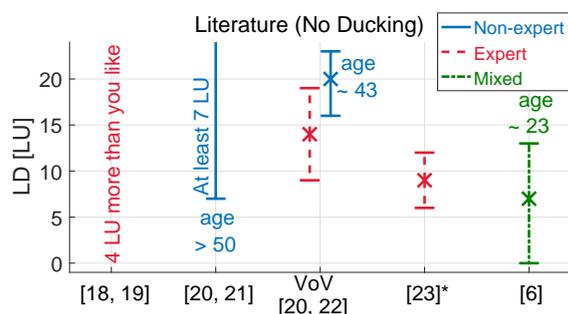
Object-based audio systems such as MPEG-H Audio solve this problem by enabling the audience to personalize the relative level of the foreground speech [14, 15, 16]. This service, known as Dialogue Enhancement, clearly increases the quality of experience for the final users [6, 17].

### 2.2 Desirable LD for the Default Mix

Even if object-based personalization is available, a default mix is needed. This should satisfy as many listeners as possible. Some works in literature investigate the LD, even if considering a constant level of the background and not in the context of ducking. These works are reviewed in the following and their main results are visually summarized in Fig. 2. If not specified otherwise, stereo signals are considered, with voice panned to the phantom center, quiet listening conditions, and high-end playback systems.

In guidelines by the BBC [18, 19], general suggestions such as the following are given: “*Be aware of background noise*”; “*Take the music down. Our research showed that bringing music down slightly in the mix allowed people across the demographic to hear dialogue, including those with certain hearing loss. Once you’re happy with your mix, try taking the music down 4dB (one point on the PPM) and see if this impacts on your creative vision. The chances are it won’t!*”.

A set of guidelines focused on speech intelligibility published by the German public broadcasters [20] suggest that the LD should be at least 7 LU and between 16 and 23 LU for VoV. These recommendations are based on the studies in [21] and [22]. In [21] a listening test is carried out where people can rate test items mixed with LD = 2, 7, 10 LU by means of a questionnaire. While listeners under the age of 50 do not show a clearly preferred condition, listeners over 50 prefer at least 7 LU for a comfortable listening experience.



**Fig. 2:** Overview on literature about desirable LD in TV audio mixes. No work takes into consideration ducking, but LD is studied as a static level difference. A modified loudness measurement is used in [23] and it is unknown to what extent it is comparable with the other values.

In [22], the focus is on VoV excerpts. These are mixed by audio engineers with LDs in the range 9-19 LU. Then, non-expert listeners between 23 and 58 years old (mean age 43) are asked to adjust the LD and to set it to their preferred level by means of a slider, starting from the LD set by the audio engineers. The results show two different groups of listeners. One group favor LDs similar to initial ones (average 14 LU), while a second group clearly prefers higher LDs (average 20 LU). Different listening conditions were also tested, e.g. with/without video, which do not led to any significant difference in the results. Hence, a LD between 16 and 23 LU is suggested to meet the preference of the most critical group.

In research by NHK [23] the balance between foreground speech and background is investigated using a variation of the ITU BS.1770 loudness, which adopts smaller time constants. It is unknown to what extent this is comparable to the other loudness values. For documentary programs, the LD chosen by 12 mixing engineers is of  $9 \pm 3$  LU. Also a few samples of musical shows and sport programs are considered. In these cases, LDs close to zero or even negative LDs are chosen by the same mixing engineers.

In [6], expert and non-expert listeners between 20 and 32 years old (median age 23) can set their preferred LD by means of the Adjustment/Satisfaction Test (A/ST). Among the test signals no VoV is present. Most of the preferred LDs lie between 0 and 13 LU, with an average of 7 LU.

Finally, in [24], the preferred speech-to-background ratios as well as the ratios that allow to only just understand everything in a sentence are investigated and predicted by means of an objective intelligibility measure. Preferred ratios range between -6 to 16 dB depending on the type of content. However, results are given as energy ratios in dB and cannot be directly compared with the other reviewed works.

All these mentioned works consider a static level of the background without considering ducking. However, ducking is widely used in real-world material. To the best of our knowledge, this paper is the first study investigating desirable LDs during ducking.

As a marginal note, numerous publications analyze music mixing preferences, which are much more documented than the ones for clear audio for broadcasting. The interested reader is referred to [25, 26] and references therein.

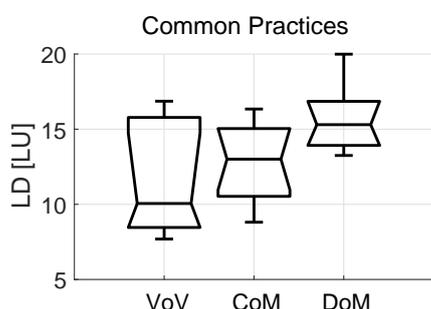
### 3 Commonly Used LDs During Ducking

In this section, we intend to gain an understanding of existing ducking techniques in TV by analyzing real-world content. Documentary programs are selected, as they are a common format in TV and they tend to feature extensive use of ducking in the audio mix. In this type of content, it is common that a foreground speech narrates some facts (making its intelligibility important) while the background tends to belong to the depicted scene or create the mood of the scene (contributing to the full enjoyment).

Twelve documentaries broadcast in the UK, Germany, and France are considered. The documentaries are heterogeneous, comprising a range of production values.

We measure the LDs for 6 VoV, 12 Commentary over Music (CoM), and 6 Dialog over Music (DoM) excerpts, while the background is ducked. *Commentary* refers to speech recorded in an audio recording studio, e.g. in a sound booth, and features professionals who speak clearly. On the other hand, (*location*) *dialog* can be less clear than commentary, as it is recorded on the scene location using portable gear and it can include location background sounds and non-professional speakers.

The full program audio files are first normalized to equal integrated loudness. Then VoV, CoM, and DoM



**Fig. 3:** Boxplots<sup>2</sup> of the LDs during ducking found in 12 documentary programs broadcast in the UK, Germany, and France. Voice-over-Voice (VoV), Commentary-over-Music (CoM), and Dialog-over-Music (DoM) excerpts are considered.

excerpts are manually selected where ducking is employed and the ducked background level is constant. For each excerpt, we isolate segments with active foreground voice and segments without foreground voice. The segments belonging to the same excerpt and voice activity class are concatenated. The LD of one excerpt is estimated as difference between the integrated loudness of the concatenated mix segments when voice is active and the loudness of the background, i.e. the concatenated mix segments when voice is not active. For LDs above 5 LU, this estimation is experimentally found to give an average absolute error of 0.6 LU (absolute error variance is 0.2) on similar synthetic excerpts.

The found LDs are shown in Fig. 3 by boxplots<sup>2</sup>. Most of the values for VoV and CoM are within the 10-15 LU range, similarly to what was measured in the signals mixed by professionals in [20, 22].

The lowest LDs are found for VoV, which is surprising considering the possible informational masking. However, voice-overs are recorded by professionals as for CoM, which is likely to enable comfortable listening in spite of the lower LDs. Higher LDs are found for DoM (14-17 LU). As location dialog can have lower clarity than commentary, audio engineers are likely to choose higher LD to compensate for this.

We also compare the usage of momentary and integrated loudness. When using momentary loudness,

<sup>2</sup>The ends of the boxes correspond to the 25/75% quantiles of the data, the central bar corresponds to the median. The vertical lines extending from the box (whiskers) indicate the minimum and maximum points within 1.5 IQR (interquartile range).

values do not vary over 1 LU with respect to the integrated loudness. This can be explained by the short length and homogeneity of the analyzed excerpts.

Even if spanning different countries, topics, and production values, the considered selection of programs is small and the found values should be corroborated on a larger sample of broadcast material in future works.

## 4 Subjective Test on LD During Ducking

This section describes the subjective test carried out to determine what LDs listeners preferred during ducking in the context of documentary programs.

**Method:** The test is a multiple stimuli test, where each stimulus (or condition) has a different LD. Participants rate their preference for each condition with a slider ranging between 0-100 and labeled each 20-points range: bad, poor, fair, good, excellent. The 9 conditions correspond to increasing LDs. The minimum LDs are between -6 and 6 LU, while the condition with maximum LDs correspond to 20-28 LU. Conditions are presented ordered by ascending LD to eliminate the participant's ability to identify what item is what and focus exclusively on ducking preference. The first condition features minimal or no ducking. The following conditions have the same background level when speech is not active, but increasing LDs when speech is active. The foreground speech has the same loudness for all conditions.

**Instructions:** The participants are told the following: *"Imagine you are hearing the presented audio pieces while watching television in your living room. Your task is to rate these different mixes (of background sounds and speech) based on your overall preference. This means that you rate the mix(es) that you would personally rather hear with the highest score."*

**Item Categories:** The test focuses on commentary only, i.e. CoM as well as Commentary over Ambience (CoA). The minimum LDs for CoA are between -3 and 6 LU, i.e. these signals are examples of the special case in which ambience is particularly loud. Most of the time in broadcast material ambience has naturally low level, resulting in high LDs. Here, we are interested in analyzing the case in which also ambience has masking potential and ducking has to be applied.

**Test Items:** The test involves 12 different items (6 CoM and 6 CoA, each with the 9 different conditions).

Variable	d.f.	$\eta^2$ (%)	p
<b>Subject</b>	18	<b>31.7</b>	<b>0.00</b>
<b>Item</b>	10	<b>15.2</b>	<b>0.00</b>
<b>Category</b>	1	<b>14.3</b>	<b>0.00</b>
<b>Age</b>	1	<b>7.1</b>	<b>0.00</b>
<b>Experience</b>	1	<b>5.3</b>	<b>0.00</b>
<b>Subject <math>\times</math> Category</b>	19	<b>4.3</b>	<b>0.00</b>
Item $\times$ Experience	10	1.3	0.24
Item $\times$ Age	10	0.9	0.58
Experience $\times$ Category	1	0.1	0.54
Age $\times$ Category	1	0.0	0.91
Age $\times$ Experience	1	0.0	0.98
Error	190	19.8	

**Table 1:** ANOVA of the preferred LDs: degrees of freedom (d.f.), effect size  $\eta^2$  (given as percentage and reporting how much of the total variability can be explained by each effect), and p-values (if lower than 0.05, we reject the null hypothesis). Significant effects are marked in bold.

All test items feature German commentary panned to the center over stereo backgrounds. Examples of ambience background are flowing water, street noise, car interior, subway hall. Music backgrounds feature no lyrics and can be categorized as soft rock, ambience music, and orchestral music. No accompanying video is shown. The sampling frequency is 48 kHz. A training item is also present before the 12 test items for a better understanding of the experiment. This item is not considered in the results. During the training phase, the subjects are asked to modify the overall volume to a comfortable level.

**Subjects:** The test involves 11 expert listeners (between 21 and 43 years old, median age 26) and 11 non-expert listeners (between 23 and 59 years old, median age 25). The expert listeners passed a listener-screening program and are verified for no hearing impairments and have high testing ability [27]. Five of them are professional audio engineers. All listeners have German as first language and have no known hearing impairments. They are volunteers and remunerated.

**Location:** Two similar listening rooms with high-end studio monitors are used. The rooms are quiet and acoustically treated so to resemble low-reverberant living rooms.

## 5 Subjective Test Results

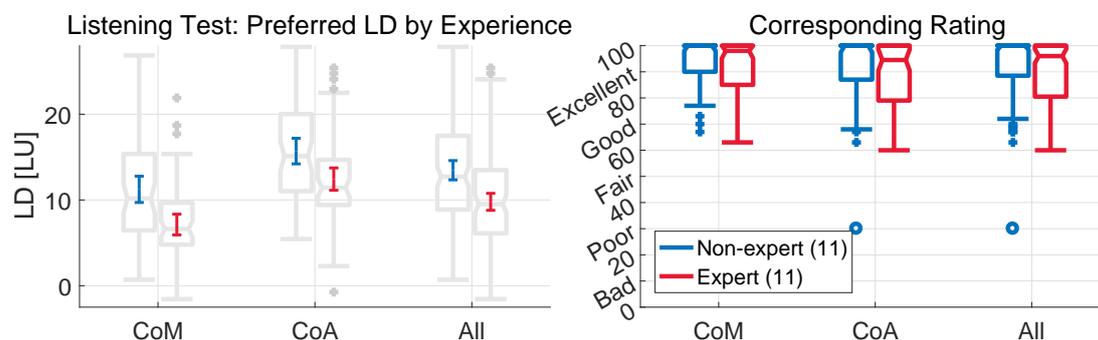
The main analysis of the results is carried out on the preferred LDs, i.e. by considering the condition(s) with the highest score for each listener and item. In a few cases, more than one condition is rated with the highest score. In this case, the average LD is taken over the two or more preferred conditions.

A nested ANOVA with five factors was carried out on the preferred LDs. The five factors are: item, item category (CoM or CoA), subject, subject age, and subject experience. The factor item is nested inside item category. The factor subject is nested inside age as well as inside experience. Item and item category are fixed factors, as they have fixed characteristics which could be used in a new experiment. Subject, age, and experience are random factors, as they are samples randomly taken from the relevant population, on which we would like to generalize.

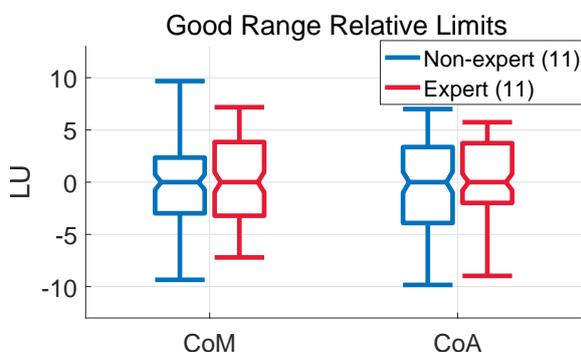
The factor age describes two groups created by taking the median age of the participants as threshold, i.e. 26. The first group comprises listeners born in 1992 or later. This group consists of 14 listeners with 24 as median age. The second group comprises 8 listeners born before 1992 with 34 as median age.

As shown in Table 1, all five factors are statistically significant. The factor subject can explain alone 31.7% of the total variability in the data, confirming that personal taste plays a fundamental role. As expected, item and category are significant factors, accounting together for the 29.5% of the total variability. The factor age explains 7.1% of the variability, even if no hearing-impaired or elderly listener is considered. Experience is statistically significant too, accounting for 5.3% of the variability. Experience is particularly interesting in our application, as TV mixes are created by experts for being consumed by non-experts. Finally, the only significant two-way interaction is between subject and category.

The 95% confidence intervals as well as the boxplots showing the preferred LDs by experience and category are shown in the left subplot of Fig. 4. The statistically significant difference between non-expert and expert listeners can be observed. Non-experts prefer higher LDs with interquartile values ranging from 6.5 to 15.4 LU for CoM and from 11 to 20 for CoA. On average, the measured difference in preferred LD between experts and non-experts is equal to 4 LU, which backs



**Fig. 4:** The subplot on the left depicts 95% confidence intervals overlapping boxplots of the preferred LDs by category and experience. For each category, non-experts (in blue) are on the left and experts (in red) are on the right. The rating corresponding to the preferred LD is shown in the subplot on the right.



**Fig. 5:** Boxplots of the relative limit values of the *good range* for each item and subject. This range includes the LDs rated above 60 and no more than 10 points below the preferred LD.

up perfectly the BBC hint of taking down the music by 4 dB [18, 19].

The right subplot of Fig. 4 depicts the ratings corresponding to the preferred LD. All the ratings lie in the “excellent” and “good” ranges, with only one exception (rating 30). This exception is due to a listener who complained about the fact that the background did not have much to do with what was being said in that item.

Beside the preferred LDs analyzed so far, we now consider the range comprising the LDs rated above 60 points (i.e. in the excellent and good ranges) and no more than 10 points below the preferred LD. We refer to this range as the *good range*. Its limit values (relative to the preferred LD) for each item and listener are shown in Fig. 5. They give a picture of the freedom that

an audio engineer would have to meet the listener preference. The interquartile ranges suggest that a  $\pm 3$  LU around the preferred LD would be still well received.

Fig. 6 visualizes the different preferences of the listeners. The different personal tastes can be clearly observed. It can be noticed that the preferred LDs for CoM are consistently lower than the ones for CoA.

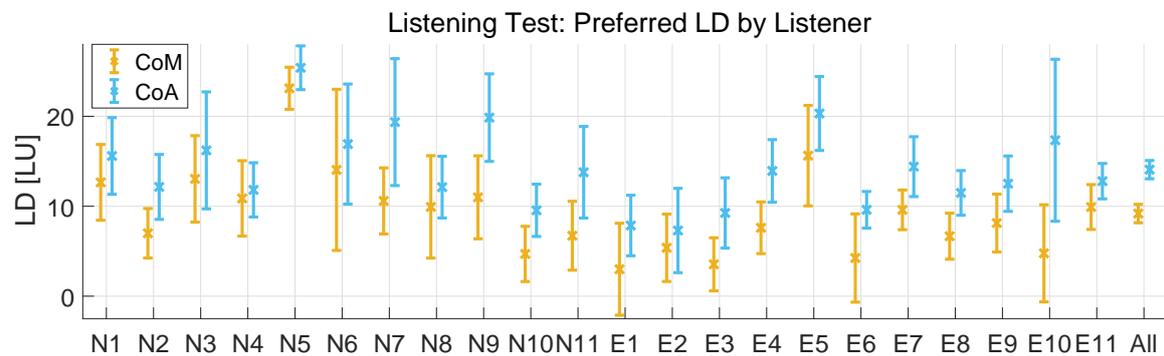
## 6 Discussion

Fig. 7 summarizes the LD values presented so far and discussed in the following, where we also introduce our recommendations.

Our results show that non-expert listeners (such as the mix consumers) prefer LDs that are 4 LU higher than the levels preferred by experts (close to the mix creators) on average. This backs up the rule of thumb suggested by the BBC to audio engineers on using LDs that are 4 LU higher than the ones they would like [18, 19]. A similar difference was documented in [22].

Trying to be more restrictive on LD values, German public broadcasters recommend at least 7 LU in general and at least 16 LU for VoV [20]. We found however that in broadcast material, it is common practice to use similar LDs for VoV and CoM, i.e. between 10 and 15 LU. Higher LDs are found only for DoM (14-17 LU), likely due to the innate lower intelligibility of location dialog.

Preferred LDs as low as 0 LU are found for expert and non-expert listeners in [6], where the median age is 23. The particularly low age of the listeners might explain



**Fig. 6:** Average and 95% confidence interval of the LD preferred by each subject for each category. For each subject, CoM (in yellow ocher) is depicted on the left and CoA (in light blue) on the right. Non-expert listeners have IDs starting with *N*, while expert IDs start with *E*.

the difference with the other reviewed works. These lower values are not recommendable for the default TV mix, but it is recommendable to make them available via the personalization offered by object-based systems such as MPEG-H Audio. The results of our listening test also show that subjects have clearly different personal preferences for the LD values.

A recommendation on the LD for the default mix has to take into consideration the preference of non-expert listeners, as they are a sample similar to the consumers of the audio mix. Our listening test shows that non-experts prefer 6.5 - 15.4 LU for CoM and 11 - 20 for CoA. It is also shown that listeners well receive a range of  $\pm 3$  LU around the preferred LD. These are large ranges, but a recommendation can be made by suggesting *at least* the median values, i.e. trying to meet the preference of the half of the population that prefers higher LDs. Satisfying the higher half of the population also make the values closer to the ones that would be needed in suboptimal listening conditions or for hearing-impaired listeners.

Hence, as shown in the rightmost part of Fig. 7, we recommend at least 10 LU for CoM. Higher LDs need to be adopted for DoM. For CoA, at least 15 LU can be recommended. Esthetically pleasing upper limits can be considered 15 LU for CoM and 20 LU for CoA (i.e. the 75% quartile of the preferences of the non-expert listeners). The range 10 - 15 LU for CoM was also observed to be commonly used in the analyzed real-world programs.

The values discussed in this paper are for rather stationary backgrounds. There might be cases and signals

where the optimal LD could deviate significantly from the recommended values. In these cases, the know-how of an experienced audio engineer is irreplaceable.

## 7 Conclusion

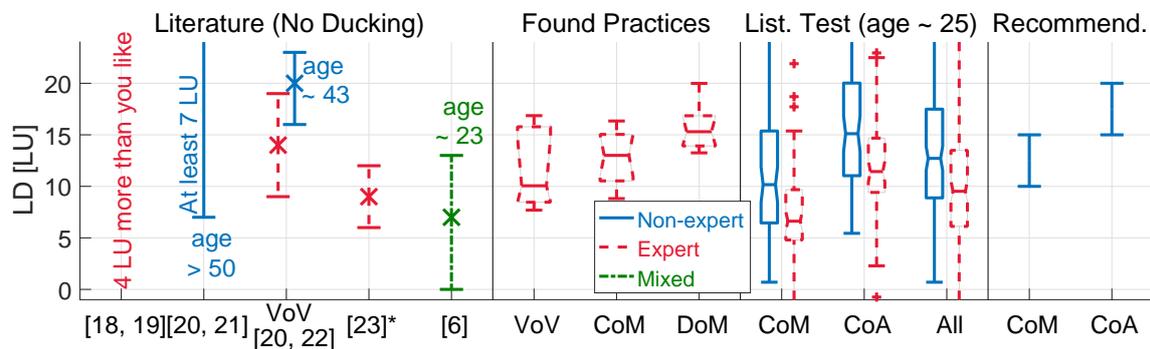
Ducking is a technique that facilitates speech intelligibility, while keeping the background enjoyable. Even if it is extensively used in TV audio, optimal values for its parameters are not documented in literature. This paper filled this void by focusing on the integrated Loudness Difference (LD) between foreground speech and background during ducking.

This was done by analyzing common practices found in a sample of TV documentaries and by carrying out a subjective test on the LDs preferred by 22 normal-hearing listeners. Our findings were compared with related works, even if these works considered a static level of the background and did not consider ducking.

The results clearly showed that only the personalization offered by object-base audio technologies such as MPEG-H Audio can meet the preferences of each subject. Nevertheless, a default mix is needed satisfying as many subjects as possible.

For a default mix which is esthetically pleasing and has clear speech, we recommend a LD of at least 10 LU for Commentary over Music (CoM) and 15 LU for Commentary over Ambience (CoA). Higher LDs need to be used for location dialog.

We believe that the know-how of an experienced audio engineer is irreplaceable, but it should be kept in mind



**Fig. 7:** Integrated Loudness Difference (LD) between foreground speech and background for the default mix in TV audio. Visual summary of literature review, common practices found in the analyzed documentary programs, results from the preference listening test, and final recommendations for Commentary over Music (CoM) and Commentary over Ambience (CoA). A modified loudness measurement is used in [23] and it is unknown to what extent it is comparable with the other values.

that non-expert listeners (such as the audio consumers) prefer LDs that are higher than 4 LU than the ones preferred by expert listeners (such as the mix creators). This difference might be even higher when considering sub-optimal listening conditions.

Future works should include subjects with higher age and age-related hearing impairment. More items, item categories, and reproduction configurations should also be studied. In addition, only the LD was investigated, which is the main parameter of ducking, but not the only one. Other parameters such as the time constants should be analyzed in future works.

## 8 Acknowledgment

Special thanks go to all who took part in the listening test and to Mariola Hatalski for taking care of them.

## References

- [1] Armstrong, M., “From Clean Audio to Object Based Broadcasting,” in *BBC Research & Development White Paper, WHP324*, 2016, available at <http://www.bbc.co.uk/rd/publications/whitepaper324>.
- [2] Tang, Y. and Cox, T. J., “Improving Intelligibility Prediction under Informational Masking Using an Auditory Saliency Model,” in *Proc. of the Int. Conf. on Digital Audio Effects (DAFx)*, 2018.
- [3] ITU-R Recommendation BS.1770-4, “Algorithms to measure audio programme loudness and true-peak audio level,” 2015.
- [4] EBU Recommendation R 128, “Loudness Normalisation and Permitted Maximum Level of Audio Signals,” 2014.
- [5] Fuchs, H., Tuff, S., and Bustad, C., “Dialogue Enhancement - technology and experiments,” *EBU Technical Review*, Q2, 2012.
- [6] Torcoli, M., Herre, J., Fuchs, H., Paulus, J., and Uhle, C., “The Adjustment/Satisfaction Test (A/ST) for the Evaluation of Personalization in Broadcast Services and Its Application to Dialogue Enhancement,” *IEEE Trans. on Broadcasting*, 64(2), pp. 524–538, 2018.
- [7] Shirley, B. and Kendrick, P., “ITC Clean Audio Project,” in *Proc. of the 116th Audio Engineering Society Conv., Berlin*, 2004.
- [8] Shirley, B. and Kendrick, P., “The Clean Audio project: Digital TV as assistive technology,” *Technology and Disability*, 18(1), pp. 31–41, 2006.
- [9] Fuchs, H. and Oetting, D., “Advanced Clean Audio Solution: Dialogue Enhancement,” *SMPTE Motion Imaging Journal*, 123(5), 2014.
- [10] Shirley, B., Meadows, M., Malak, F., Woodcock, J., and Tidball, A., “Personalized Object-Based

- Audio for Hearing Impaired TV Viewers,” *J. of the Audio Engineering Society*, 65(4), pp. 293–303, 2017.
- [11] Walton, T., Evans, M., Kirk, D., and Melchior, F., “Does Environmental Noise Influence Preference of Background-Foreground Audio Balance?” in *Proc. of the 141st Audio Engineering Society Conv., Los Angeles*, 2016.
- [12] Mapp, P., “Intelligibility of Cinema & TV Sound Dialogue,” in *Proc. of the 141st Audio Engineering Society Conv., Los Angeles*, 2016.
- [13] Florentine, M., “Speech Perception in Noise by Fluent, Non-native Listeners,” *J. of the Acoustical Society of America*, 77(S1), pp. S106–S106, 1985.
- [14] Herre, J., Hilpert, J., Kuntz, A., and Plogsties, J., “MPEG-H 3D Audio - The New Standard for Coding of Immersive Spatial Audio,” *IEEE J. of Selected Topics in Signal Processing*, 9(5), pp. 770–779, 2015.
- [15] Kuech, F., Kratschmer, M., Neugebauer, B., Meier, M., and Baumgarte, F., “Dynamic Range and Loudness Control in MPEG-H 3D Audio,” in *Proc. of the 139th Audio Engineering Society Conv., New York*, 2015.
- [16] ISO/IEC, “Information technology – High efficiency coding and media delivery in heterogeneous environments – Part 3: 3D audio,” International Standard 23008-3:2018, Second Edition, 2018.
- [17] Torcoli, M., Herre, J., Paulus, J., Uhle, C., Fuchs, H., and Hellmuth, O., “The Adjustment/Satisfaction Test (A/ST) for the Subjective Evaluation of Dialogue Enhancement,” in *Proc. of the 143rd Audio Engineering Society Conv., New York*, 2017.
- [18] BBC Editorial Guidelines, “Hearing Impaired Audiences,” 2011, available at <http://downloads.bbc.co.uk/guidelines/editorialguidelines/pdfs/hearing-impaired.pdf>.
- [19] BBC Academy, “Clear Sound: Best Practice Tips,” 2017, available at <https://www.bbc.co.uk/academy/en/articles/art20130702112135255>.
- [20] *Sprachverständlichkeit im Fernsehen, Empfehlungen für Programm und Technik (Intelligibility in Television, Recommendations for TV Program and Technique)*, ARD/ZDF, 2014, (in German) available at: <https://www.irt.de/webarchiv/showdoc.php?z=NzE0MSMxMDA2MDE4I3BkZg==>.
- [21] Ebert, E. and Bodenseh, E., “Arbeitsergebnisse und die daraus resultierende Guideline (*Speech Intelligibility in TV: A Guideline*),” in *Proc. of the 28th Tonmeistertagung - VDT Int. Conv.*, 2014, (in German).
- [22] Liebl, T., Goossens, S., and Krump, G., “Verbesserung der Sprachverständlichkeit, speziell bei Voice-Over-Voice-Passagen (*Improvement of Voice-Over-Voice Speech Intelligibility in Television Sound*),” in *Proc. of the 28th Tonmeistertagung - VDT Int. Conv.*, 2014, (in German).
- [23] Komori, T., Takagi, T., Kurozumi, K., and Murakawa, K., “An Investigation of Audio Balance for Elderly Listeners using Loudness as the Main Parameter,” in *Proc. of the 125th Audio Engineering Society Conv., San Francisco*, 2008.
- [24] Tang, Y., Fazenda, B. M., and Cox, T. J., “Automatic Speech-to-Background Ratio Selection to Maintain Speech Intelligibility in Broadcasts Using an Objective Intelligibility Metric,” *Applied Sciences*, 8(1), p. 59, 2018.
- [25] Fenton, S., “Automatic Mixing of Multitrack Material Using Modified Loudness Models,” in *Proc. of the 145th Audio Engineering Society Conv., New York*, 2018.
- [26] De Man, B., Reiss, J., and Stables, R., “Ten Years of Automatic Mixing,” in *Proc. of the 3rd Workshop on Intelligent Music Production*, 2017.
- [27] Schinkel-Bielefeld, N., “Training Listeners for Multi-channel Audio Quality Evaluation in MUSHRA with a Special Focus on Loop Setting,” in *Proc. of the 8th Int. Conf. on Quality of Multimedia Experience (QoMEX)*, IEEE, 2016.