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A Study of Psychoacoustic Mechanisms of Fear in Horror Sound Design

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Abstract. Sound in horror movies and games can be used to change a person's perception of a scene before a visual threat appears. The five psychoacoustic factors of horror sound design in this paper are auditory roughness, nonlinearity, dissonance and pitch instability, low-frequency sound, and temporal contrast. Previous studies have shown that these factors cause fear and anxiety through various ways, such as increased auditory prominence, reduced predictability, tonal instability, spatial pressure and expectation. Then, based on the above research, a 90-second procedural horror-music piece was created using two layers of wind, thunder and a main melody. Rather than using a single frequency, interval or distortion device as the standard "formula for fear", the project generates tension through changes in texture, pitch, low-frequency energy and silence. According to the analysis, the effect of these features depends on the time and interaction; stable background materials serve as references, and later modifications are more prominent due to contrast. As no large-scale listening experiment was conducted, this project is presented as a literature-informed design application rather than an experimental verification of causality.

Keywords: psychoacoustics, horror sound design, auditory roughness, nonlinearity, low-frequency sound

1. Introduction

Sound is used in horror films to some extent. A closed room, an empty corridor or a still picture is not required to generate tension. After an unidentifiable wind sound, a distant low-frequency vibration, an abruptly interrupted melody, or an irregular transient are added, people may still perceive the same picture differently. Sound can indicate that a place extends beyond the frame and suggest that an event has not yet occurred will take place. Therefore, in horror films and games, sound is not merely added to the picture. It directly contributes to building the framework of threat, distance, space and time.

From a production standpoint, creating a good-sounding but odd one is not difficult. Distortion, noise, pitch shifting, reversal, filtering, modulation and dissonant intervals are all likely to sound strange. Familiarity, coldness and fear are not the same. In procedural horror-music course project, wind, thunder and a main melody needed to be organised in a code-based environment such as Nyquist/SAL. A problem soon arose in the initial stage of production: although individual sounds had been assigned functions, when several layers were combined, the result was occasionally only a

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dense mess and not more frightening. This problem shifted the focus of the present paper from the question of "which horror sound effects should be added?" to the question of "which acoustic features may affect listeners, and why might they work?".

Psychoacoustics connects measurable acoustic characteristics with subjective hearing experiences. The four groups of mechanisms for this paper are related to the project: roughness and nonlinearity; dissonance and pitch instability; low-frequency sound; and silence and dynamic contrast. What are the acoustic features associated with fear or anxiety, how do they affect listeners, and what can be learned from this to improve procedural horror-music design?

These mechanisms will be used to guide the production decision for a 90-second procedural program. The previous research results are taken as design references rather than fixed rules, because a single acoustic parameter cannot always induce fear in all circumstances.

2. Related work

Psychoacoustics is the study of how the physical characteristics of sound are perceived by people [1]. Valence and arousal are often employed in emotion research to indicate whether a person feels good or bad, and how intensely that feeling is experienced [2]. Horror sounds are often associated with a negative valence and relatively high arousal, but fear should not be viewed as a single response. Anxiety, suspense, fear of a clear threat, and a sudden startle can all produce different listening experiences [2].

It will affect the design of horror sound. A continuous low-frequency background, for example, can provide a longer sense of pressure, and a sudden sound with a strong dynamic change may be more suitable for startle [3]. Therefore, the impact of a sound also depends on what it is used for in a particular place [1], not just on its sound qualities.

Roughness of the acoustic signal is also a type of feature. Arnal and others have studied the acoustic features of human screams and found that screams fall in a particular area of acoustic roughness. Similar features can also be found in artificial alarm sounds [4]. Based on the above research, it is known that a rough surface is more likely to be noticed and considered more severe by people. Therefore, the cause of a scream cannot be attributed to either a high pitch or a high volume. Rapid acoustic fluctuations are also causes of the coarse nature of sound and are mentioned in [4, 5].

Nonlinear Acoustic Characteristics Have Also Been Studied in the Context of Emotional Response. Blumstein, Bryant and Kaye have investigated how non-linear sounds are used in music and what emotions these sounds can make people feel [6]. Human and animal vocalisations under stress can have features such as subharmonics, sudden frequency shifts, and irregular spectral components. Film music can also have the same characteristics.

Not all non-linear sounds are associated with fear. It has different effects in all the environments where it occurs. Distortion can be used to indicate an unstable or uncontrollable sound source in a horror film, but the same kind of distortion may also be a natural attribute of the sound in electronic or rock music. Therefore, nonlinearity should be considered in conjunction with the musical and narrative context rather than being treated as an independent signifier of fear.

Trevor, Arnal and Frühholz have further investigated the connection between human screams and horror movie music [7]. They studied how people's voices differ from various kinds of film music, and found that some horror music has a harsh sound that is similar to screams. It can be assumed that some horror music is intended to create a sense of fear without needing to depict a scream in the film. From the perspective of sound design, the research can be used to connect a typical feature of human vocal communication with techniques used in horror music [7, 8].

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Although the above studies provide some reference points, they are not entirely suitable for actual sound production. Different studies do not always use the same definitions for fear, anxiety, terror or arousal. The experimental materials and methods may also be unavailable. More importantly, laboratory research generally focuses on a small number of acoustic parameters, but in a real horror soundtrack, there are often multiple elements such as environmental sounds, music, dialogue, reverberation, and visual information simultaneously.

There is also a practical problem in applying the above results to procedural audio. A psychoacoustic concept cannot always be mapped directly to a single parameter in Nyquist or SAL. For example, knowing that roughness can increase auditory salience does not tell the composer at what modulation speed or depth, or what sound source, to use in a particular work. For this reason, the studies mentioned in this paper are mainly used to provide theoretical support for design decisions and are not fixed numerical rules.

3. Psychoacoustic mechanisms of horror sound

3.1. Roughness and nonlinearity

Roughness is related to the perceived unevenness and instability of a sound. When the amplitude or spectral content of a sound changes rapidly, it is less smooth in character and may be more noticeable. Arnal and others have determined that the roughness of human screams is strongly reflected in modulation rates of about 30-150 Hz [4]. This range is a measure of the speed of sound variation, not the tone of a low-frequency sound. Therefore, simply adding a bass tone in the range of 30-150 Hz would not achieve the same perception effect [1, 4, 5].

This division is required for the purpose of application. Amplitude modulation, dense frequency components, noise and other irregular textures can be used to add roughness. The Size of the Roughness Must Also Be Limited. If a noise is very uneven and lasts for a long time, one may gradually get used to it, and then one will find it tiresome to hear. In a short horror composition, it may therefore be more effective to increase the roughness gradually or add it at specific times rather than using it at full strength throughout the entire work [1, 5].

Nonlinearity can be understood in the same way. Distortion, subharmonics, sidebands, noise components and sudden frequency changes will make the sound less stable and less predictable. When the above features appear in a previously stable sound, it may be that there has been an abnormal change in the sound source. This can be employed in horror sound design to have a different tone of voice and, at the same time, to create a sense of the uncanny through the unexpected.

Timing is more suitable for the procedural horror project mentioned in this paper than applying a large number of distortions. A relatively stable wind sound can be used to create an environment first, and then roughness or other nonlinear features can be added to produce an obvious change in the soundscape. Therefore, the instability is due to both the acoustic feature itself and the contrast between the earlier and later states.

Nonlinear sounds may have distortion, subharmonics, sidebands, noise or chaotic components, and sudden frequency jumps. The above features reduce the regularity of a stable harmonic system. For the listener, a sound source that was originally stable but suddenly exhibits discontinuities, extra harmonics or changes in pitch is often perceived as an anomaly in the source's state. Blumstein and others believe that such elements can enhance the sense of emotional arousal, but this is highly context-dependent [6]. Therefore, the design of the procedure should also address "how much

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distortion" is used. Consider when the distortion occurs, whether a stable reference was available before this time, and how long the change persisted.

3.2. Dissonance and pitch instability

Horror music often uses minor seconds, semitone clashes, tritones, beating, and unresolved harmony, but these intervals are not always signs of fear. Their other roles are to reduce tonal stability and prediction. Musical-theoretical dissonance should not be confused with psychoacoustic sensory dissonance. The first is related to tone, style and culture; the latter is closely connected with the interaction of simultaneous spectral components. The two often overlap in horror music, but they are not the same [9, 10].

Pitch drift, slight detuning, chromatic alteration, abrupt rise in pitch, irregular pause, and unresolved end all make listeners feel uncomfortable about the development of the tune. Rather than using random notes, a shorter piece can also be written well with a main theme and minor changes. Listeners first learn a pattern, and then when that pattern is broken, it is no longer expected. If the melody is completely random from the start, there will be too little stable structure for the listener's expectation to be meaningfully broken [11, 12].

3.3. Low-frequency sound

Low-frequency sounds are commonly used in horror to show heaviness, distance, a large sound source, and spatial pressure. Thunder, mechanical rumbling and continuous low-frequency noise can make a place feel larger and heavier, and some low-frequency energy may also be felt in the body as vibration. A small number is not always indicative of fear. The perceived noise will be influenced by the sound pressure level, duration, low-frequency response of headphones/speakers, room environment, etc. Research on very-low-frequency sound also frequently requires high sound-pressure levels and controlled experimental environments. It is therefore inappropriate to promote the idea that frequencies below 20 Hz necessarily make listeners afraid [1, 3].

Too much low-frequency content in practice also leads to masking. If the wind, thunder, sustained drones and the lower register of the music all occur in the same area continuously, it will be too noisy. A practical way is to give different functions to low-frequency energy: sustained wind can establish the spatial basis, thunder is related to a strong transient low-frequency energy, and the melody should avoid continuous conflict with the environmental layers in the same band. Low frequency then transmits scale and hierarchy rather than accumulating energy [1].

3.4. Temporal factors

A type of material used for horror sound design is silence. Silence is not inherently scary; rather, it is that this work have lost track of time. The audience expects a problem to arise; therefore, when there is a sudden drop in sound, it becomes suspenseful. A fleeting one is thus likely to be remembered more vividly. A short pause before the thunder, an impact or a sudden sound can be added to increase the contrast more effectively without raising the overall level [11, 12].

Dynamic Contrast also depends on the connection between the previous and current. If the preceding section is already very loud, a technically larger peak may still not be startling. Sudden starts after a long silence, irregular intervals between sounds, and unplanned noises are all violations of continuous sound. Temporal Factors are also a type of horror sound design. A sound does not have the same effect every time it is produced. It also depends on what the listener has heard before

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to some extent. Roughness or strong low-frequency energy may be less prominent if they persist for an extended period of time. On the other hand, the same feature will attract more attention when it suddenly appears after a long period of silence and stability. Therefore, in the Design of this project, this work have been considering not only what kinds of sounds to use but also when they should be presented.

Therefore, it does not need to be the case that all psychoacoustic features are enhanced simultaneously. In fact, it will be too noisy for all the soundscape. A relatively good result can be achieved by leaving a sufficient contrast between the sections. Low-frequency ambience can be used first to create a sense of place. The background will be relatively quiet for a short time before the thunder. If the texture of the thunder is relatively coarse and the decay is uneven, then there will be more differences. A weak tune can be added between the large sound events to give it a sense of unease. In this way, the different sounds are related, but they do not all demand the listener's attention at the same time [11, 12].

As shown in Table 1, the psychoacoustic characteristics mentioned above serve different perceptual purposes and should not be regarded as the same.

Table 1. Main psychoacoustic features and their design functions

Acoustic Feature	Primary Mechanism	Possible Perceptual Effect
Roughness	Increases auditory salience	Alertness, discomfort
Nonlinearity	Increases unpredictability	Abnormality, loss of control
Dissonance / pitch drift	Weakens musical prediction	Tension, unease
Low-frequency sound	Increases weight and spatial scale	Pressure, threat
Silence / dynamic contrast	Violates temporal expectation	Suspense, startle

4. Application to a procedural horror-music project

4.1. Project design

The nine-minute procedural horror-music work uses the psychoacoustic phenomenon of two wind layers and thunder, along with a primary melody.

The first wind sound mainly serves to provide an environment. It has more energy in the low-frequency range and varies gradually with time. The first is to reduce the noise level of the surroundings and lower the overall pressure to minimise attention. For this reason, the movement of this layer is also relatively simple. The stable character of the first wind sound also serves as a reference for the more obvious changes introduced later in the work.

The second wind layer is relatively unstable, and thus has larger amplitude modulation and spectral variation. It will be added later when the tension is higher, and no new sound source will be introduced at this time.

The Range and Volume of the combined two wind layers need to be taken into account. There is too much overlap of the layers; therefore, some of the background environment has been hidden. Some spectral separation is thus required. At the same time, a similar reverberation and spatial processing can be applied to both wind sounds to give the impression that they are in the same acoustic environment.

Thunder is a type of sound that will occur in the project. It is relatively less stable than a continuous wind layer and has a higher proportion of low-frequency energy. A small amount of

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subharmonic content can be added to increase the sense of weight, and noise components and a longer decay can be used to create a sense of distance and space. The above features help to distinguish the thunder from the background noise of nature.

A fluctuating state of the thunder is also to be achieved in the Design. The first shock needs to be relatively larger than the background, and then it gradually decreases in size. Over-compression will reduce the difference between the two stages and cause a more metallic sound of thunder. For this reason, it is more suitable to have a distinct dynamic relationship between the attack and the decay for the project. The environment will be reduced slightly before the lightning appears; thus, it will be relatively darker and require a smaller increase in peak value. After the first impact, there will be some reverberation and a noise tail for a short time before the wind background gradually increases again.

The primary tune has a different purpose than the layers of the environment. Wind and thunder are responsible for creating the environment and some large-scale sound effects; there is no individual melody. It offers a musical reference for the listener that can be changed later. Therefore, the tune is not the result of entirely random pitch generation.

The first is a relatively simple presentation of the main theme. Minor seconds, chromaticism and a small number of tritones are used at certain places to reduce the sense of tonality. Do not use these intervals continuously, or too many unstable intervals will reduce the structural integrity of the melody and make the motif less recognisable. The first tune can be relatively simple, and then some modifications can be added to it.

Several controlled variations are used in the later part when the melody returns. These are minor pitch variations, irregular pauses and changes in register. Only a small number of parameters are changed at one time so that the connection to the original motif is still recognisable. As a result, the later version has maintained the character of the original tune but is more unstable.

The end of some melodic phrases has also not been resolved. Rather than returning to a steady final pitch every time, some phrases end on a slightly unstable note or have a small rise or fall in pitch near the end. Therefore, the tune will not achieve a full sense of closure, and the tension will be carried over to the next part. Gradually changing a recognisable motif in this project is more suitable than completely random pitch generation, as it offers a clearer contrast between stability and instability.

4.2. Overall structure

The five sections of the 90-second work are arranged to gradually increase the tension and are not full-blown at the start.

The first 20 seconds are low-frequency winds used to create a mood and provide a general sense of pressure. From 20 to 45 seconds, the main tune is introduced in a fairly clear way, and it will be familiar to the audience. From 45 to 65 seconds, the second wind layer enters, and there will be some changes in the music. Without reaching the peak, the Soundscape will not be stimulating. The strongest part is around 65-80 seconds, and at this time, thunder, a rougher texture, stronger low-frequency energy and larger dynamic changes are all more pronounced. As the earlier sections are more stable, these changes will be more noticeable. In the last 10 seconds, the active layer is gradually reduced. Reverberation, a low-frequency decay or an unstable final pitch, occurs instead of a full resolution.

As shown in Table 2, the whole structure is relatively stable in the background and then becomes more unstable before not being fully resolved.

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Table 2. Structure of the 90-second procedural horror-music piece

Time	Main Material	Function
0–20 s	Low-frequency wind	Establish sustained anxiety and spatial background
20–45 s	First appearance of main melody	Establish the identity of the piece
45–65 s	Second wind layer and melodic variation	Increase instability
65–80 s	Thunder, roughness, stronger dynamics	Create the tension peak
80–90 s	Gradual reduction of sound	Leave an unresolved ending

5. Conclusion

The roles of several psychoacoustic characteristics in horror sound design are presented in this paper, including roughness, nonlinearity, dissonance and pitch instability, low-frequency sounds, silence and dynamic variations. Based on the relevant literature and the procedural horror-music project, it can be seen that fear is not caused by a single acoustic feature. Different sound materials serve different purposes in the work. The wind sounds in this project are mainly used to create and change the atmosphere gradually; thunder is used to create a more noticeable sound effect; and the main melody gradually becomes unstable through changes in pitch and structure. In addition to raising the volume of various sound elements, one can also adjust when they occur and how different parts are presented to maintain a reasonable loudness difference and make the construction of tension more gradual.

This study is not perfect either. As the project did not have a large-scale listening experiment, the current design methods are mainly based on previous studies and practical observations during the production process, and they cannot yet be considered general rules for horror sound design. Different Playback Systems, listening environments and individuals' differences in hearing can all affect the final perception. Some psychoacoustic concepts still need to be verified empirically after their application to particular Nyquist or SAL parameters. Future work will be a small-scale A/B listening test based on the current project to compare factors such as roughness, low-frequency energy, silence before thunder, and pitch drift. Then, according to the feedback from the listeners, change the above parameters. Thus, the actual effects of the different sound-design methods can be observed more closely and more specific references provided for future procedural horror sound design can be offered.

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