

Original Article

A Study on the Comparison of Characteristics of Three Types of Whistle Sounds

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Abstract - A whistle is a type of tool that produces sound by blowing among various signaling tools. The whistle has evolved structurally to produce sharp and strong sounds, and due to its characteristics, it is effectively used in fields where clear intentions are expressed. The main fields where whistles are used are as referees in sports games, when the police control the surroundings, and when individuals are notified of danger. In addition, whistles used in each field are classified into unique whistles with individual characteristics according to their purpose. This paper is a study to verify whether representative whistles used according to their purpose in the three fields presented above are effectively utilizing the sound characteristics appropriate for the situation. For the study, the sounds of the three representative whistles were compared and analyzed. As a research method, the sound characteristics of the three whistles were scientifically analyzed, and the listeners' responses were investigated and compared. As a result, a referee whistle in sports games, a police whistle, and a self-defense whistle showed strong sound signals and unique tones in that order. In addition, the sounds of the three whistles have been learned through experience by the general public, so they can be easily distinguished by field and verified to be used appropriately for the situation.

Keywords - Whistle, A referee whistle, A police whistle, A self-defense whistle, Sound characteristics, Experience, Verify.

1. Introduction

Humans realized that they could send signals with sound even at distances that were difficult to transmit with voice, and they created tools that made sounds and developed them into musical instruments. At first, they created percussion instruments such as drums that made sounds by striking them, and then they created wind instruments that made sounds by blowing them, and string instruments that plucked or plucked the strings. Among them, the whistle, which was used as a signal by blowing grass stems, animal bones, or bamboo stems, can be said to be the beginning of wind instruments.

Although the whistle developed into a wind instrument, the whistle itself is effective in making a stronger and louder sound momentarily, unlike other instruments. It has developed into a signaling tool necessary for warnings or cautions. Signaling tools that have developed through this process to inform situations with sound include not only whistles but also sirens, trumpets, and horns. In this paper, we compared the sound characteristics of three types of whistles used for signaling: a referee whistle in sports games, a police whistle, and a self-defense whistle, and conducted research to verify whether each whistle is being used appropriately for its intended purpose in the relevant field. As a research method, the sound of three whistles was recorded, and the sound characteristics were analyzed and compared in various ways.

Next, a MOS test was conducted in which 10 lay listeners were blindly told the sounds of these three whistles and asked to guess their purpose. To record the sounds of the three whistles, a digital recorder, H2 from ZOOM, which uses an SD card as a recording medium, was used.

2. Whistles

There are many tools that have been used to send signals to each other since the days of primitive humans, but among them, the tool that makes a sound by blowing developed into the current whistle. The early tools that made a sound by blowing grew in size and developed into wind instruments by adding holes to control the scale. However, the whistle is used solely as a tool for signaling and has been modified to suit various fields.[1]

2.1. Origin of the Whistle

The whistle was born when early humans began to realize that they could use sound to send signals to each other. It is presumed that they first began to produce sounds by tapping them, and gradually, they began to produce sounds by blowing animal bones or horns, conches or shells, or branches or plant stems. Also, judging from the discovery of ceramic whistles in ancient ruins, it seems that they were actively interested in and researching whistles to the extent that they knew the scientific principles of whistles. Also, tools that produce



sounds by blowing, such as whistles, grew in size and developed into wind instruments as they learned that the sound would change when blown by drilling holes. However, whistles themselves had the unique characteristic of being able to transmit high-pitched sounds over long distances, so they were developed separately for their original purpose of signaling.

In primitive times, whistles were used as signals between tribes during hunting or war, and as they became industrialized, they were used to control workers at work sites, train athletes in sports events, and make judgments during games. Whistles became more sophisticated and began to be mass-produced in the 19th century in England when whistles were made. In this way, the whistle is a sound tool that has been used continuously in various fields and will continue to develop in the future because it can induce unity of action and send signals with meaning depending on the situation.

2.2. The Principle of the Whistle

The form of the whistle was initially simply blowing grass stems or bamboo branches with the mouth to make sounds, but as scientific and physical principles were gradually applied, the performance improved to the point where whistles were made of ceramics. Recently, even electronic whistles that were operated by buttons were released. The whistle was made of a small, hollow tube designed to let air escape after blowing it

in. It was easy to hold with a finger, and special devices were installed inside and on the part where the air was blown in to make the sound's pitch, volume, and tone unique. The early whistles were made by putting a small, hard ball in a small tube, and when blown, the ball moved and made a sound; they were used in all situations regardless of the field. Later, they gradually changed the structure to a different type of whistle, such as a tube-shaped whistle, and used it according to the field. Also, as steam engines were invented through industrialization, whistles were used in steam locomotives that operated using high-pressure air emitted from the machine. Later, as steam locomotives developed into diesel and electric trains, whistles also developed into electronic horns.

2.3. Types of Whistles

A whistle is a sound tool suitable for giving instructions, warnings, or judgments to many people in a wide space. In special cases, a whistle is used for musical performances, but since the pitch cannot be adjusted by itself, it is also used as a sound effect in the middle of a performance. Any whistle can be used in all situations, but these days, whistles are made with different sound characteristics and used individually in different fields according to the situation. Whistles can be broadly divided into three types according to the use field. The three types of whistles are whistles for referees, mainly used in sports, whistles for police, and whistles for self-defense, carried in daily life to alert people of danger.

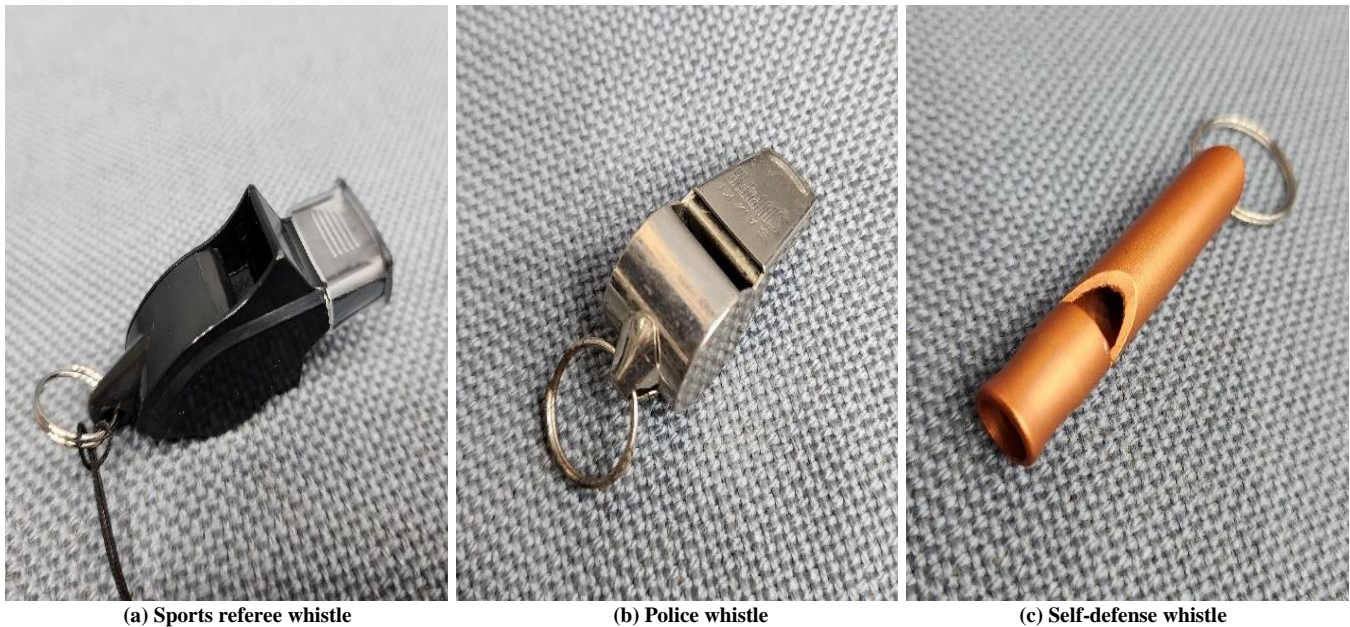


Fig 1. Three types of whistles

A whistle is blown loudly and long to warn and blown short several times to caution, but it is more effective to set rules for each field of use. Figure 1a. A sports referee whistle is a whistle used to notify players and spectators of the start and end of a game in a large stadium and to warn or caution players. Sports stadiums are either indoors or outdoors and are

large in size, so when a game starts, it is very noisy due to the cheers and noise of the spectators, so a clear and strong sound is needed to send a signal for the game. Figure 1b. A police whistle is a whistle that has been used for a long time and is the most commonly seen signaling tool. Police whistles come in plastic and metal materials, and the sound is somewhat

different depending on the material. Plastic materials produce a slightly softer sound than metal materials, and metal materials produce a slightly sharper sound than plastic materials. Since metal materials produce a higher-pitched and brighter sound, they are used more often than plastic materials these days.

However, there are concerns that metal materials can rust or become conductive, so they are produced with stainless steel materials that do not rust easily and are non-conductive. Figure 1c. A self-defense whistle is a personal whistle used to request a rescue from people around you when you are in danger of various crimes that may occur in a quiet place or on a dark street at night. Self-defense whistles are mainly carried by women and used when danger is detected, and they are said to be quite effective. Although self-defense whistles have not been around for very long, there are many self-defense whistles on the market with various designs and improved performance.[2]

3. Comparison of Three Types of Whistle Sound Characteristics

The reason for comparing the sounds of three whistles, a sports referee whistle, a police whistle, and a self-defense

whistle in this study is to verify whether the sounds of each whistle currently used in each field are being used appropriately for the situation. In order to analyze the sounds of the three whistles above, the sounds of the three whistles had to be recorded first. To record the sounds of the three whistles, ZOOM's H2 digital recorder was used.

The recording was conducted in a KBS radio drama production studio with good soundproofing. The sounds of the three whistles were recorded by blowing them once long and three times short from a distance of 5 meters from the recorder. The recorded sounds of the three whistles were scientifically analyzed and compared for their sound waves, sound energy, and sound frequency distribution. In addition, a blind test method called the MOS test was conducted with 10 listeners to listen to the sounds of the three whistles and guess the purpose of each whistle. For scientific sound wave analysis, time domain analysis was performed to analyze the sound waves of three whistle sounds over time, spectrogram analysis was performed to analyze sound energy, and spectrum analysis was performed to compare the pitch of each sound frequency band. For this scientific analysis, Adobe's Audition 3.0 program was used. Frequency component analysis uses the FFT concept.

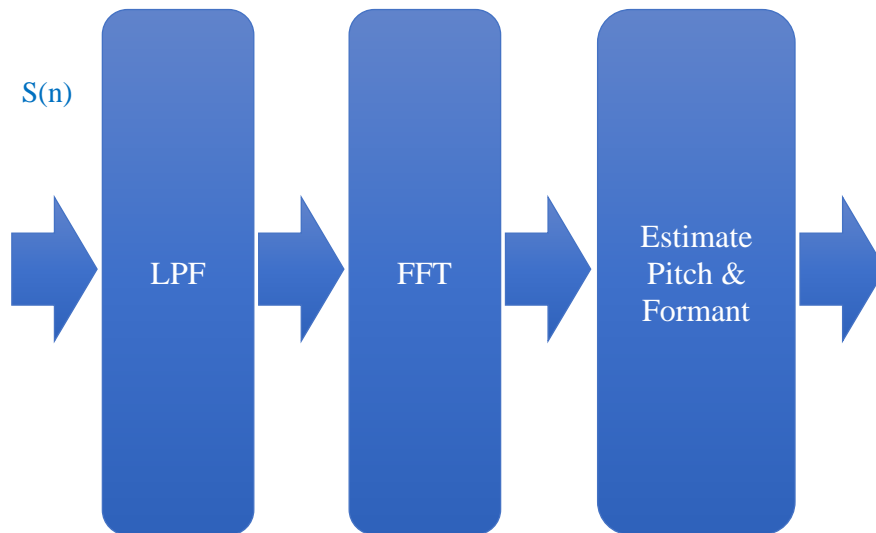


Fig 2. FFT diagram for obtaining sound information

Figure 2 above is a diagram showing the process of digitizing the analog sound signal of the whistle using the Fast Fourier Transform (FFT). The first step in digitizing the analog signal is to perform a low-pass filtering operation (LPF: Low Pass Filter) that passes the low-frequency signal while filtering out the noise that exists in high frequencies.

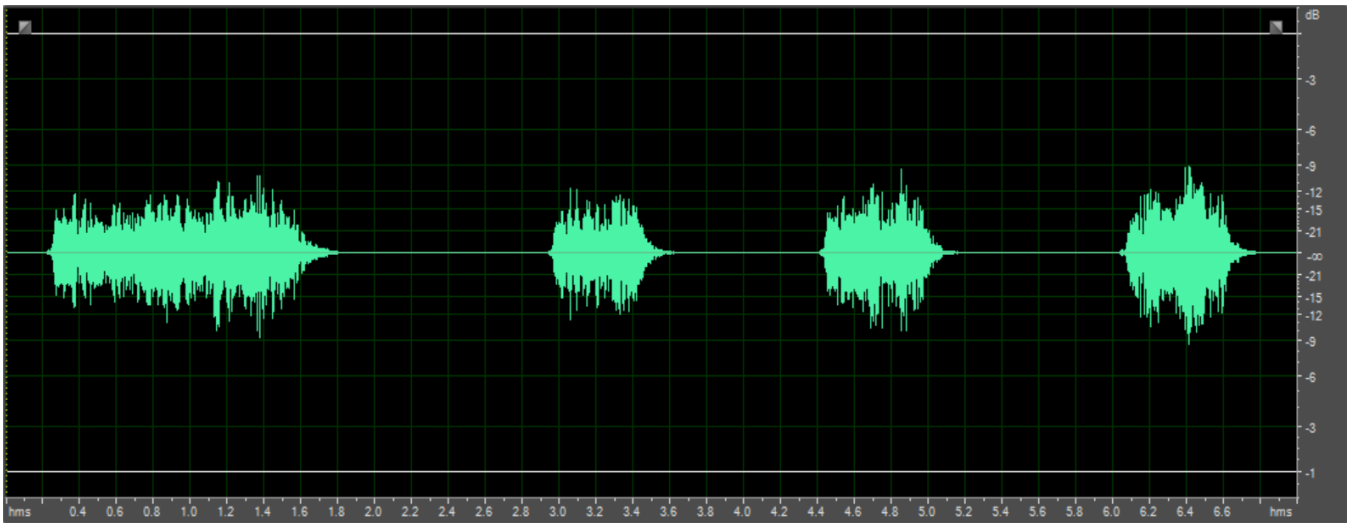
Next, the sound signal is converted to be easy to analyze using the Fast Fourier Transform. Through this process, a foundation for analyzing the pitch and formant of the sound frequency is established.

3.1. Time Domain Analysis

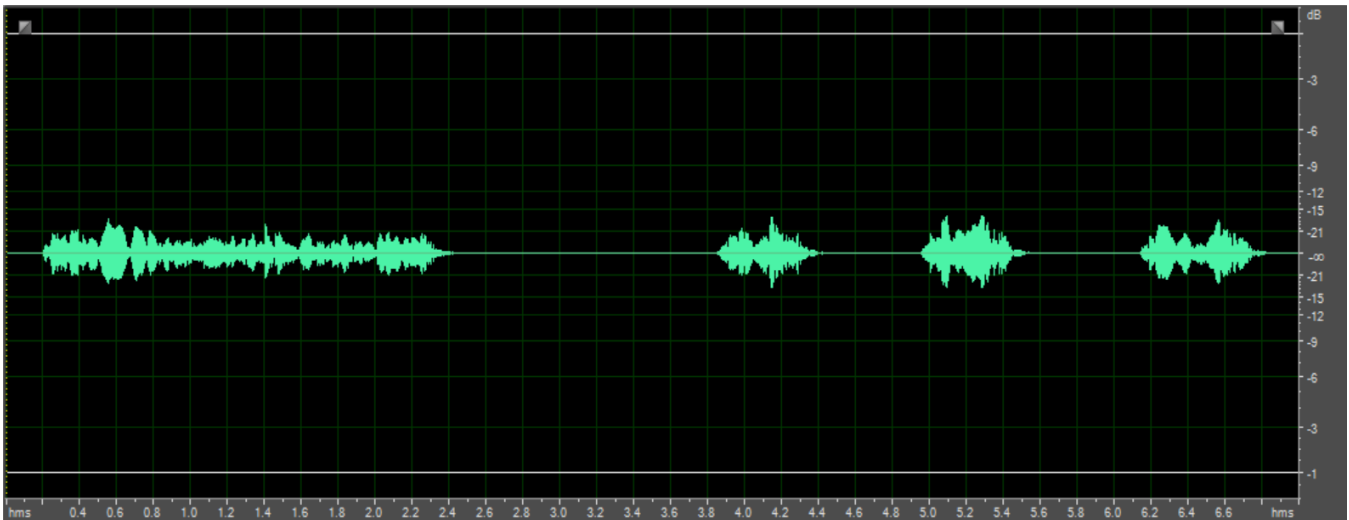
As the first step for the acoustic analysis of the three whistle sounds, time domain analysis was performed. The sounds of the three whistles (a. Sports referee whistle, b. Police whistle, c. Self-defense whistle) were graphed in the time domain. The changes in the sound amplitude of the three whistles over time were analyzed using the time domain graph, and the results were examined. Figure 3. Looking at the time-domain graphs of the three whistles, we can see that the sound amplitude is formed largely in the following order: a. Sports referee whistle, b. Police whistle, c. Self-defense whistle.



a. Sports referee whistle



b. Police whistle



c. Self-defense whistle

Fig 3. Time-domain graphs of three types whistles

- (a) The Sports referee whistle is designed to transmit sound to players located far away more loudly than the noise of cheering spectators in large outdoor stadiums or indoor stadiums, so this paper can see that the sound amplitude is expressed strongly in the time-domain graph.
- (b) The Police whistle is designed to transmit signals louder than the surrounding sounds in a wide area, such as a downtown street, so this paper can see that it is expressed with a thick sound amplitude.
- (c) The Self-defense whistle is a whistle designed to call for help from those around it rather than transmit sound over a wide area, so although the overall sound intensity is low, it is a whistle that produces a high-pitched sound to increase transmission. [3]

3.2. Spectrogram Analysis

In order to analyze the sound energy of the three whistle sounds, this paper analyzed the spectrogram graph. This paper derived the spectrogram graphs in the order of the three whistle sounds: a. Sports referee whistle, b. Police whistle, c. Self-defense whistle. We analyzed the energy change by frequency band for the sound components of the three whistles using the spectrogram graph and examined the results.

Looking at the energy distribution spectrogram graph in Figure 4, first of all,

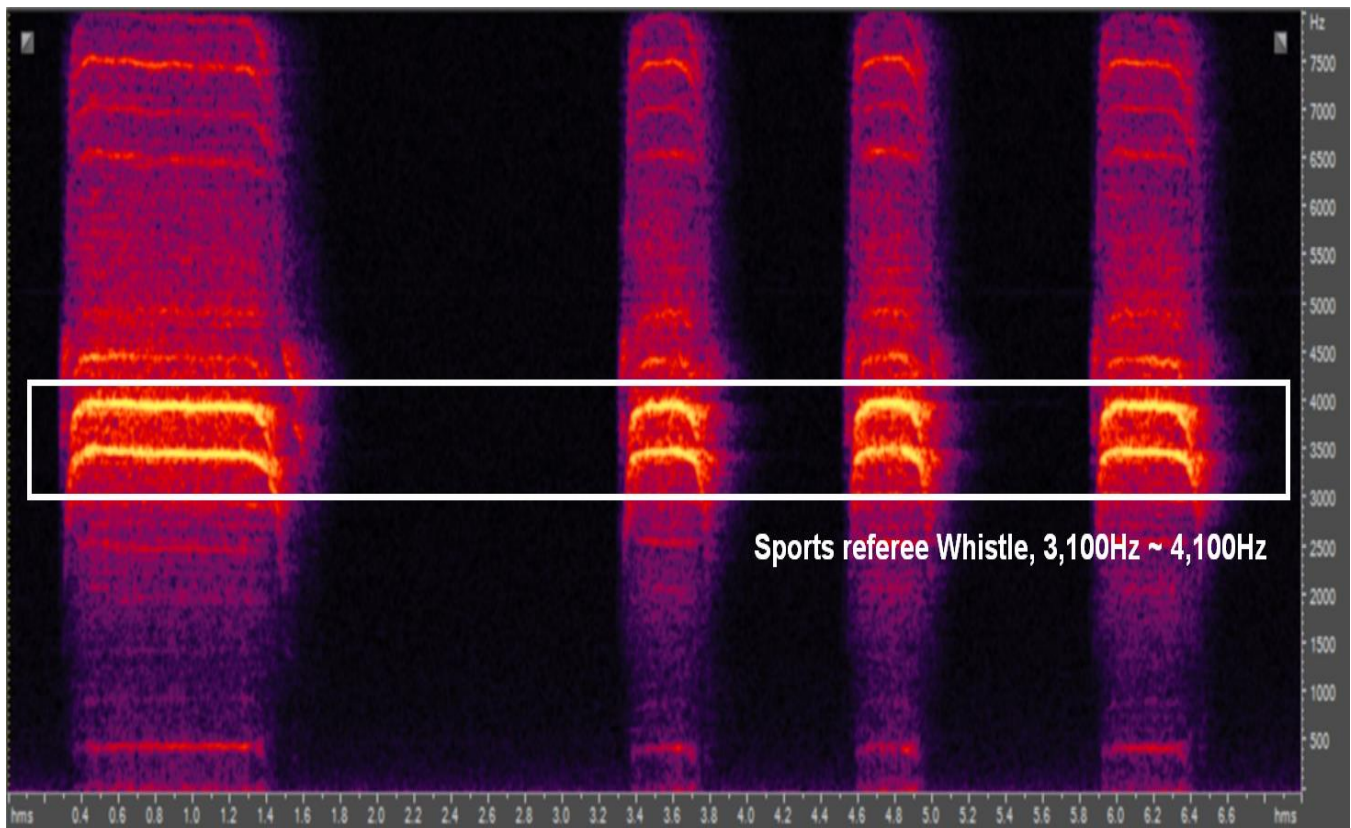
- (a) The sports referee whistle forms weak energy around 500

Hz and shows the strongest energy among the three whistles, around 3,100 Hz and 4,100 Hz. Also, although it is relatively low in the relatively high-frequency ranges of 6,500 Hz, 7,000 Hz, and 7,500 Hz, it has the highest energy among the three whistles.

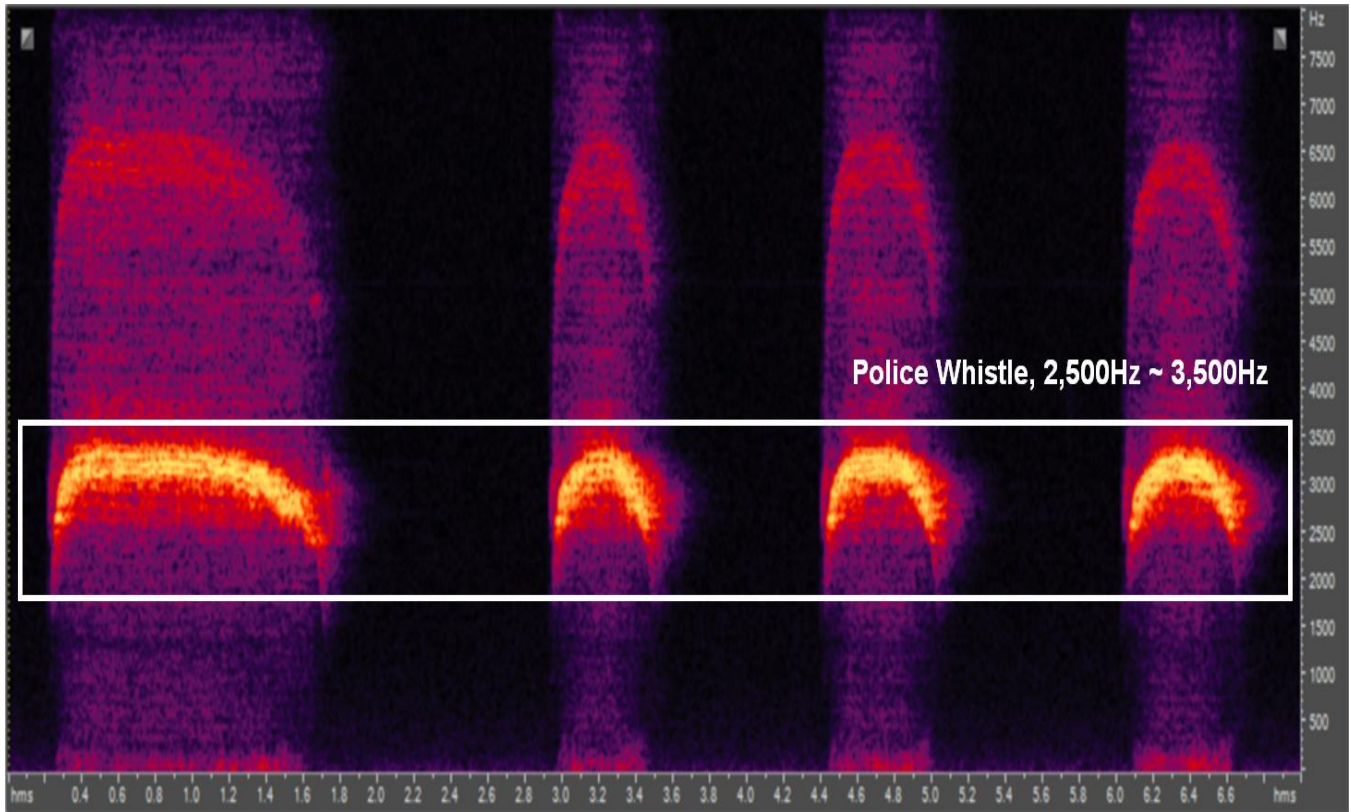
- (b) The police whistle forms thick energy in a wide range from 2,500 Hz to 3,500 Hz, centered around 3,200 Hz, different from the graphs of the other two whistles. Lower energy is formed around 6,500 Hz in the high-frequency band compared to the other two whistles.
- (c) The self-defense whistle shows energy that is somewhat weaker and wider than the sports referee whistle, around 2,100 Hz to 2,400 Hz, and energy that is narrower and higher than the center frequency of the police whistle can be seen. In the relatively high-frequency ranges of around 4,700 Hz and 7,100 Hz, it forms energy stronger than the police whistle and similar to the sports referee whistle.

Looking at the energy distribution characteristics of each of the three whistles,

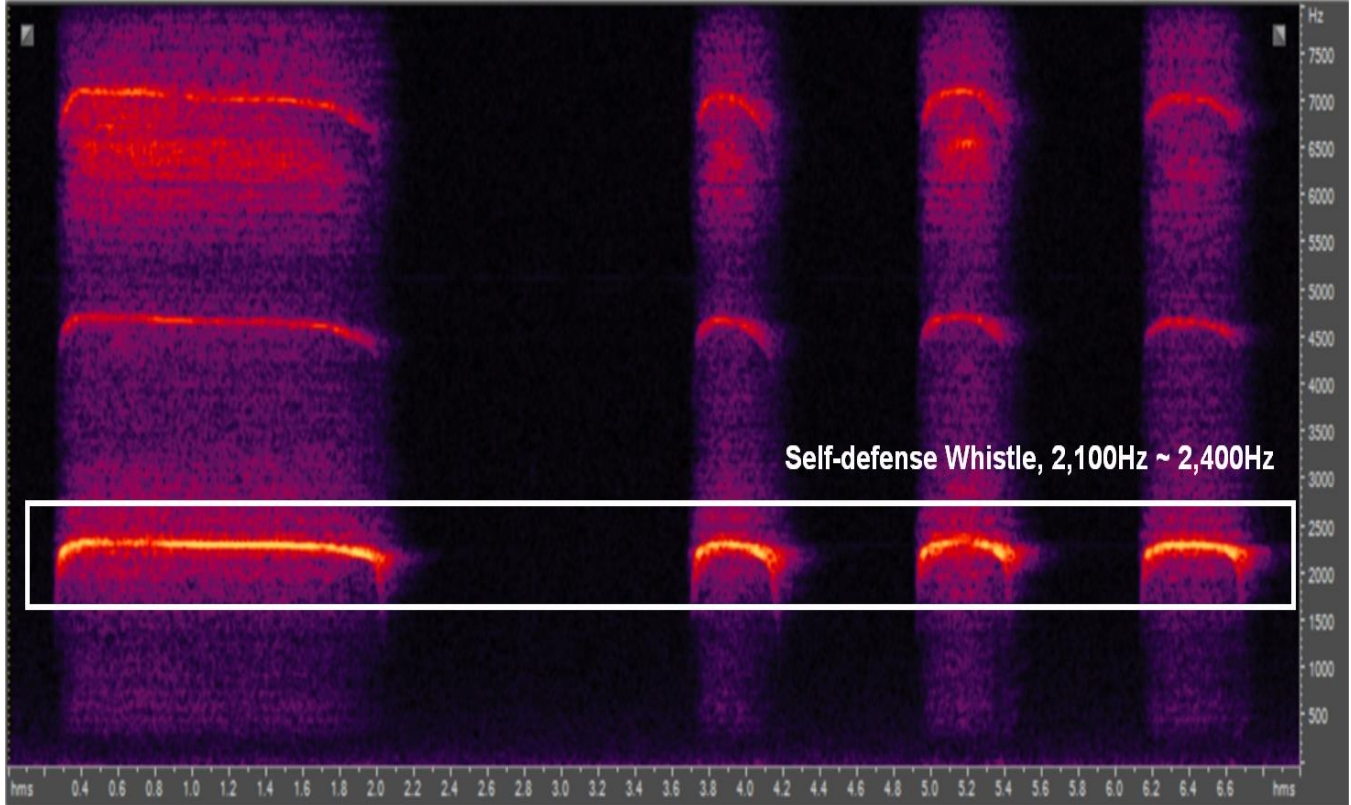
- (a) The sports referee whistle distributes strong energy evenly across the largest frequency band, followed by
- (b) The police whistle shows strong energy in two relatively small frequency bands but forms a thick energy band, so it can be seen to have a heavier and more intense sound characteristic than the sounds of the other two whistles.[4][5]



(a) Sports referee whistle



(b) Police whistle



(c) Self-defense whistle

Fig 4. Spectrogram graphs of three types whistles

3.3. Spectrum Analysis

Through spectrum analysis of three whistle sounds, This paper investigated the sound characteristics of each whistle sound by frequency. The sounds of three whistles: a. Sports referee whistle, b. Police whistle, c. Self-defense whistles

were analyzed by deriving spectrum graphs and compared with each other. Spectral analysis can analyze and compare what kind of graph each whistle sound shows within the audible frequency band and what kind of frequency band it is distributed in.

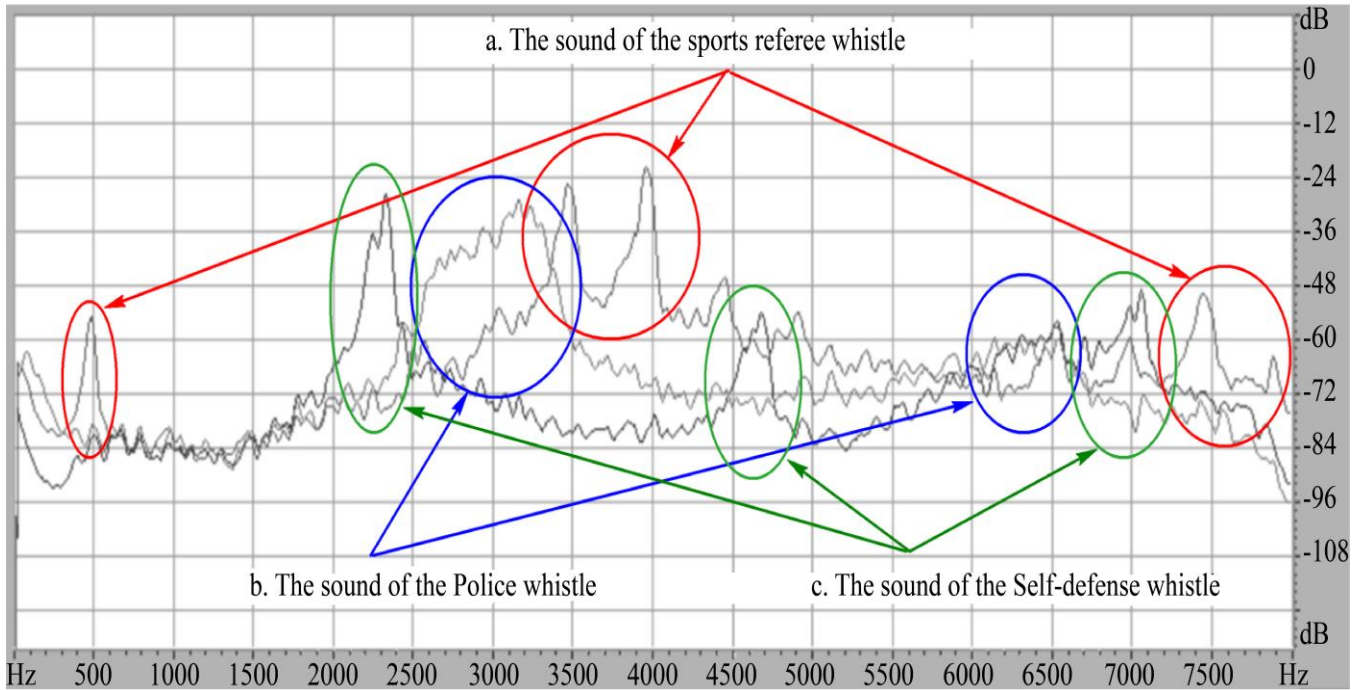


Fig 5. Spectrogram graphs of three types whistles

Looking at the results of the frequency graph comparison of the three whistles shown in Figure 5.

- Sports referee whistle shows the highest frequency graphs across the 500Hz low-frequency band that stimulates emotions, the 3,000Hz to 4,000Hz band, which is the most sensitive range in the human audible frequency range, and the 7,000Hz to 7,500Hz high-frequency band that transmits strong and high sounds, so it can be said to have the best transmission power. Next,
- Police whistle expresses a strong sound in a thick frequency band from 2,500Hz to 3,500Hz and also produces a clear sound in a thick range in the high-frequency band from 6,000Hz to 6,700Hz, showing the second-best transmission power among the three whistles. The police whistle is a whistle that maintains the old-fashioned ball-inserted style, but it shows excellent performance with wide transmission power and strong sound.
- Self-defense whistle has a pitch clearly defined in the 2,000 Hz to 2,500 Hz band, a pitch defined in the 4,500 Hz to 5,000 Hz band, and a pitch near 7,000 Hz, and it expresses a clear sound evenly across the frequency band. However, because the frequency range of the pitch is narrow, it shows the lowest performance among the three whistles in terms of wide transmission power.

3.4. MOS Test

The MOS Test (MOS Test: Means Opinion Score Test) is a simple survey method mainly used for call quality tests. It is an opinion verification test that has been verified for reliability in all walks of life because it allows the subjects to express objective and sincere opinions even with a small number of subjects. Recently, it has been used to survey people's opinions in various fields. The MOS Test was also used in this study to determine the sound characteristics of three whistles. The MOS Test on the three whistle sounds was conducted in a format where 10 listeners listened to the sounds of the sports referee whistle, police whistle, and self-defense whistle blindly and matched the whistle sound to each purpose and appealed their opinions. The MOS Test is a method to verify whether each whistle sound is being used properly according to its intended use through listeners who actually have to receive the whistle signal in their daily lives, so it can be said to be the most realistic verification method. This MOS Test was conducted in a rather unique way. Ten listeners were presented with three whistle sounds in random order without being told what the sounds were in advance. They were asked to distinguish which whistle each whistle sound was and indicate which whistle they felt was the most intense. The initials of the alphabet were used to indicate the Sports referee whistle as 'S' for Sports, the Police whistle as 'P' for Police, and the Self-defense whistle as 'D' for Defense. In addition,

they were asked to choose the whistle that they felt had the strongest transmission power among the three whistles and indicate it with 'S', 'P', or 'D'. As a result of conducting the MOS Test, the following results were derived: Table 1. The

sound of the sports referee whistle was correctly guessed by 7 out of 10 listeners, showing a high recognition rate of 70%. The sound of the police whistle was correctly guessed by 8 out of 10 listeners, showing a recognition rate of 80%.

Table 1. MOS Test for sound of three types whistles

Listeners/Whistles	Sports Referee Whistle	Police Whistle	Self-Defense Whistle	The Most Powerful Whistle
Listener 1	S	P	D	S
Listener 2	S	P	D	S
Listener 3	S	P	D	S
Listener 4	D	P	S	P
Listener 5	S	P	D	D
Listener 6	S	P	D	S
Listener 7	D	S	P	D
Listener 8	S	P	D	P
Listener 9	P	D	S	P
Listener 10	S	P	D	S

Selection indicators: sports referee whistle: 'S', police whistle: 'P', self-defense whistle: 'D'

This seems to be because the police whistle is the whistle that has been used the longest and is the most widely recognized whistle. The self-defense whistle also showed a high recognition rate of 70%, with 7 out of 10 listeners correctly guessing it. This result suggests that the general public has been listening to each of these whistle sounds in their daily lives according to the situation and thus has chosen the fields in which these three whistles are used appropriately. In addition, the sound selected as the most intense among the three whistle sounds was confirmed to be the sports referee whistle by 5 people, the police whistle by 3 people, and the self-defense whistle by 2 people. Through this opinion, it was confirmed that the listeners recognized that the whistle used in loud and large spaces such as sports stadiums was the most intense sound. The sound of the police whistle used in the noise of traffic on city streets was the second most intense sound. The sound of the self-defense whistle was perceived as a stimulating sound that could be accurately transmitted to bystanders in the quiet of the night or a secluded place.[6]

4. Conclusion

In this paper, we compared the sound characteristics of three whistles used in real life, including the sports referee whistle, police whistle, and self-defense whistle, and conducted a study to verify whether each whistle is being used appropriately for its purpose in the relevant field. As a research method, we recorded the sounds of the three whistles, scientifically compared and analyzed their sound characteristics, and conducted a MOS Test in which 10 lay listeners listened to the sounds of the three whistles in a blind format to match their purposes. As a result of verifying the

sounds of the three whistles, first, the sports referee whistle, which can clearly inform players of the start and end of the game and send warnings or cautions in a large outdoor stadium or indoor stadium where there is a lot of cheering or noise from the spectators, was verified to be the most powerful sound.

Second, the police whistle, which can send signals to drivers or pedestrians in an environment such as a busy and noisy downtown street due to traffic noise during rush hour, although it is lower than the sound of a sports referee whistle, was verified to be the second most powerful sound. Third, it was verified that the self-defense whistle, which shows concentration enough to effectively call for rescue from people around when encountering a dangerous situation at night or in a crime-ridden area, produces a high-pitched and unique sound, although it is weaker than the sports referee whistle or police whistle.

In addition, in the MOS Test, a verification method targeting listeners, it was verified that the sounds of the three whistles were all appropriately used in the necessary fields based on the opinions of 10 listeners. As a result, the sound characteristics of the three whistles through scientific analysis were verified as sounds appropriate for the situations in each field. It was also found that the whistle sounds used in each field have been naturally learned and imprinted on the general public through experience, so most people have adapted to them and are recognizing them well and living with them. From that perspective, it was judged that the sounds of these three representative whistles are each well used for their respective purposes, so the purpose of this study was achieved.

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