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How Do University Literature Students Understand the Learning Contents of Sound Taught at School?

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The present study aims at exploring university students' knowledge of sound, especially their understandings of sound phenomena taught in formal science classrooms at junior high school. The participants are 30 university students attending literary courses. They were selected because they were considered to have had few opportunities to formally learn about sound since junior high school and their understandings would be strongly influenced by everyday experiences. The participants were individually interviewed for approximately 25 minutes and asked to answer the four questions related to sound phenomena, all of which had been taught at junior high school. According to the results, more than half of the participants gave scientifically correct answers in spite of the relatively few opportunities open to them for physics classes. Also, most of the participants who provided scientifically incorrect responses explained their answers based on incorrect intuitive knowledge that seemed to have been acquired through everyday life. The intermediate knowledge was found between intuitive and scientific knowledge.

Keywords: intuitive knowledge, sound, science education, university literature student

Introduction

Researchers of cognitive development have explored children's and adults' knowledge of the world (e.g., "shape of the Earth" (Vosniadou & Brewer, 1992); "heat" (Erickson, 1980); "electric current" (Cohen, Eylon, & Ganiel, 1983). Osborn and Freyberg (1985) argued that children before formal learning acquire some knowledge through experiences in everyday life and that was called as "children's science". Also, they stated that children's science is one of the reasons why learning science at school is sometimes difficult. That is, the everyday knowledge that students bring to science classes is often inconsistent with it and obstructs their understanding. Furthermore, Chi, Slotta, and de Leeuw (1994) argued that revising incorrect intuitive knowledge is necessary to understand scientifically correctly and achieve a deeper understanding.

Some researchers, however, have reported that revising intuitive knowledge is difficult even when counterevidence against it is presented (e.g., Chinn & Brewer, 1993). According to Dreyfus, Jungwirth, and Eliovitch (1990), some people change their intuitive knowledge to another incorrect version when encountering a counterintuitive situation. These findings showing the robustness of students' prior knowledge suggest that conveying scientific knowledge alone would hardly make them change their existing knowledge. In order for students to correctly understand scientific knowledge, it is necessary not only to explore the type of knowledge they acquire through everyday experiences, but also to investigate how they understand the contents of learning

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at school. Although many researchers have expressed concern over the former issues, little is known about the latter. Studies shedding light on this side are also necessary for utilizing research findings in practice.

The topic of this study is sound. One reason is that there have been few findings of students' knowledge of sound. Furthermore, in Japan, sound is taught at junior high school (12- to 15- year-olds) though people have experienced sound phenomena before birth (Parncutt, 2006). This considerable period of time between an initial experience and first formal instruction would make intuitive knowledge of sound robust and resistant to change.

From the scientific perspective, sound is a vibratory process. However, the previous studies reported a tendency to consider sound as a kind of object not only in children before formal learning (Mazens & Lautrey, 2003; Lautrey & Mazens, 2004), but also in university students (Linder & Erickson, 1989; Wittmann, Steinberg, & Redish, 1999). For example, Mazens and Lautrey (2003) asked 6-, 8- and 10- year-old children why we could hear some voices or noises outside even when we were inside the house. Most of the children answered that there were tiny holes in the wall of the house. Mazens and Lautrey argued that these answers reflected children's intuitive understanding that some space is necessary for sound to travel and concluded that children tended to consider sound as a kind of object. Also, Linder and Erickson (1989) reached a similar conclusion by asking university physics students to explain several everyday phenomena related to sound. Most of the tasks used in the previous studies were generated based on sound phenomena that people may encounter in everyday life. However, it has not yet been examined how such knowledge affects the understanding of scientific knowledge of sound taught in science classes.

In order to take advantage of the findings from researches to improve science education, it is necessary to examine how the contents of learning and intuitive knowledge of sound are related. Thus, the present study aims to investigate how university literature students understand the properties of sound taught in science classes. University literature students were targeted because most of them have had few opportunities to formally learn about sound since junior high school and their understanding would be strongly influenced by everyday experiences. In the Japanese science course, four main contents are taught: (1) Sound is the vibration of a medium such as solids, liquids and gases; (2) Sound is a longitudinal wave; (3) Sound velocity is about 340 m/sec in the air; and (4) Sound's volume and pitch change depend on the sounding body. The questions used in the present study were generated mainly based on these four contents.

Method

Participants

Thirty Japanese university students majoring in literature participated in the present study (13 males and 17 females). Mean age was 21.2 years old (SD = 1.04, range 19-23). Eleven out of 30 had attended physics classes during high school.

Questions

In order to examine how university literature students regarded sound phenomena taught at school, four types of questions were generated, based on the course of study in Japan (see Appendix).

Medium. Sound is a vibratory process, that is, sound exists by vibrating matter such as solids, liquids and gases. The participants were asked to answer whether the following eight items propagated a sound vibration: air, water, wood, rubber, glass, iron, paper and fabric. In addition, they were asked whether a sound could exist in outer space. For each item, the participants were also required to explain their answers.

Propagation process. Sound is a dilatational wave, and thus, air molecules do not move in the direction of a sound's travel. A task used in the study of Wittmann, Steinberg, and Redish (1999) was translated into Japanese and presented to the participants. They were asked to answer how a dust particle moved in front of a loudspeaker when a sound was emitted. Also, they were required to explain their answers.

Propagation velocity. A sound velocity is affected by its medium, temperature or atmospheric pressure but not by its direction. The participants were presented with two pictures where the distance from a sound source and the medium of sound were equivalent. In one picture, a sound goes down, and in the other picture, it goes up. The participants were asked which sound would go faster. Again, they were required to explain their answers.

Amplitude and frequency of sound. Science textbooks in Japan state that the amplitude of sound only affects its volume and frequency only affects its pitch. The relationship between amplitude and frequency is mutually exclusive in science classes. The participants were shown a series of pictures of a string instrument where either of the power to pluck, cord length, string tension or size of string was altered. The participants were asked how sound would change in each situation, and why they thought so. In addition, they were asked to draw a sound wave on a grid sheet for each question.

Procedure

The participants were individually interviewed for approximately 25 minutes. The questions were always asked in the same order as described above. The protocols of the participants were recorded.

Analyses

Participants' protocols were transcribed and their answers were classified into whether scientifically correct or not. Then, how they regarded sound was examined based on explanations of their answer. For the question of medium, from the scientific perspective, all the eight items (air, water, wood, rubber, glass, iron, paper and fabric) could be a medium of sound, and the sound could not travel through outer space. For the question of the propagation process, when they answered a dust particle would slightly bounce on the spot, they were identified as having correct knowledge of the sound propagation process. Any other types of answers were regarded as scientifically incorrect. For the question of propagation velocity, the correct answer is that both sounds would travel at the same speed since they are not affected by their directions. For the question of amplitude and frequency of sound, the correct answers were as follows. When the power to pluck is strengthened, the volume would increase but the pitch would not change. When a cord is lengthened or the size of string is thickened, the pitch would be lowered but the volume would remain unchanged. And when a string tension is tightened, the pitch would become higher but the volume would not change.

Results

First, the influence of high school physics classes was analyzed. However, there was no significant bias in all questions used in the present study between those who had taken physics classes and those who had not. Thus, the following analysis lumps them together. In the first section, the participants were classified according to whether their answers were scientifically correct or not. Then, their explanations were analyzed to explore their ideas that led to their answers.

Answers to Each Question

Medium. Figure 1 shows the results of each question for the medium of sound. Only six participants (20.0%) correctly answered all the nine items (Fisher's exact test, two-tailed, $p < 0.01$). Then, the binominal analysis was applied to each question except for air because all of the participants answered that air could be a medium of sound. Significantly more participants considered water and glass as a medium of sound and answered that sound could travel even in outer space (all $ps < 0.01$). In contrast, rubber could not be a sound medium ($p < 0.01$). There was no significant difference in the number of participants who answered correctly and incorrectly for wood, paper, iron and fabric.

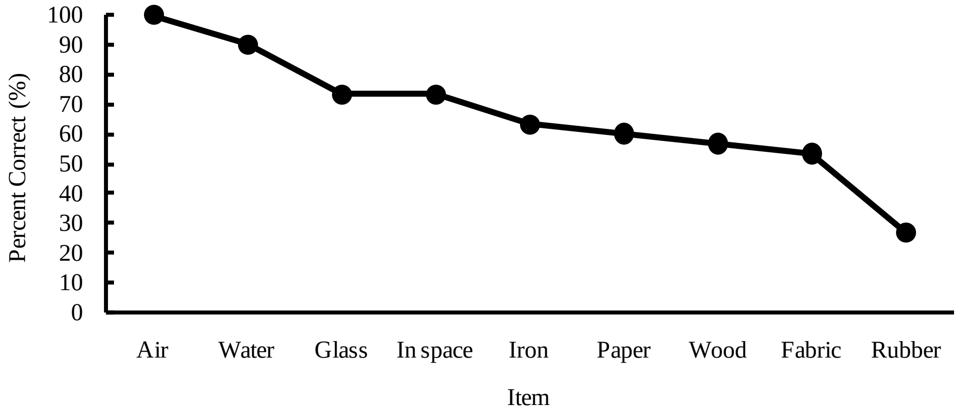

Figure 1. Percent correct of the questions for medium of sound.

Propagation process. Only five participants (16.7%) answered correctly (see Table 1). Twenty-two participants (73.3%) answered a dust particle would move away from a loudspeaker, and two participants (10.0%) answered there would be no effect of sound on the dust particle. The Chi-squared test was applied to these three types of answers and revealed a significant bias among them ($\chi^2_{(2)} = 21.80$, $p < 0.01$).

Table 1

Number of Each Answer in the Questions for Sound Propagation Process and Velocity

Question	Answer	N	Percentage (%)
Propagation process	Correct		
	A dust particle would slightly bounce at the spot.	5	16.7
	Incorrect		
	A dust particle would move away from the speaker.	22	73.3
	A sound would have no effect on a dust particle.	3	10.0
Velocity	Correct		
	Sound velocities in both pictures are equal.	12	40.0
	Incorrect		
	Sound would travel faster when it goes down than it goes up.	18	60.0

Propagation velocity. From the scientific perspective, there is no effect of traveling direction on sound propagation velocity. Twelve participants (40.0%) answered correctly that sound velocities in the two pictures would be equal. Eighteen participants (60.0%) answered that the sound traveling down would be faster than going up and there was no participant who answered the reverse (see Table 1). Fisher's exact test (two-tailed) showed that there was no significant bias between them.

Amplitude and frequency of sound. For the questions for amplitude and frequency of sound, both the participants' verbal answers and drawings were rated according to whether they were scientifically correct or not (see Figure 2). Fifteen participants (50.0%) gave a scientifically correct verbal answer to all the questions (Fisher's exact test, two-tailed, *ns*), and 12 (40.0%) of them also drew a correct sound wave in all the four situations (Fisher's exact test, two-tailed, *ns*). The participants were classified into the following four categories in each situation: (1) Both the verbal answer and the drawing are correct; (2) Only the verbal answer is correct; (3) Only the drawing is correct; and (4) Both the verbal answer and the drawing are incorrect. Chi-squared test revealed the significant bias among categories in the question for power to pluck ($\chi^2_{(3)} = 23.07$, $p < 0.01$) and string tension ($\chi^2_{(3)} = 9.20$, $p < 0.05$) and the marginal significant bias in the question for string length ($\chi^2_{(3)} = 7.07$, $p < 0.10$). However, there was no significant bias among categories in the question for string size ($\chi^2_{(2)} = 4.20$, *ns*). In all types of questions for amplitude and frequency of sound, there were more participants whose verbal answers and drawing were both correct and less participants who were correct only in answers but not in drawing.

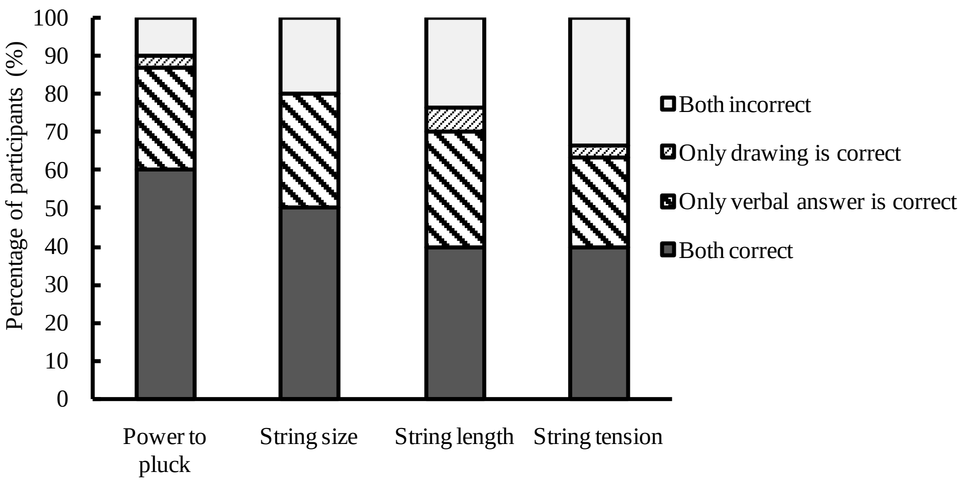

Figure 2. Percentage of the participants for each category in the four questions for amplitude and frequency of sound.

Explanations of Each Question

In order to explore what type of knowledge led to their answers to each question, the participants' explanations were analyzed. For all the questions, most of those who provided scientifically correct answers explained in terms such as "just by guessing" or "I think I was taught so at school" and it seemed difficult to determine how these participants conceptualized the sound phenomena. Thus, the following analyses mainly focused on the explanations by those who did not answer scientifically correctly.

Medium. All the participants considered air as a medium of sound and most of them explained this based on the fact that we usually hear others' voices or music through the vibration of air. And three participants who answered that water could not be a medium of sound commonly gave an everyday example, that was, we could not hear our voices in the sea or a swimming pool.

For wood, rubber, wood, glass and iron, the typical explanation of why they could not propagate sound was that solids or thick objects could not be vibrated. Another typical explanation was that they had few or no space for sound to travel. This explanation would reflect their idea that sound could vibrate only air, and thus, objects that seemed to have no space for air could not be a medium of sound. In addition, especially for wood and rubber, some participants explained, based on their everyday experiences, that they could not propagate sound but have a sound-absorbing property.

For paper and fabric, two typical explanations were found. One was that they are too soft or thin to have air in them. And another was that since both of them are made of wood, they also have a sound-absorbing property.

Finally, for hearing sound in outer space, all of the participants who answered correctly referred to the absence of a medium, whereas those who gave incorrect answers referred to their experiences of watching movies where astronauts talked with each other in outer space or talked to us on earth. Since the question did not ask directly whether sound could travel in a place that was a vacuum, it would be impossible to decide whether approximately one third of the participants did not understand that a medium is necessary for sound to travel. However, these explanations provided evidence that some university literature students explained the phenomena related to sound based on their everyday experiences, even though they had learned about them in their classes.

Taken together, four typical patterns of incorrect explanations were found: The first idea was that they quoted some of their experiences to explain their answers; The second idea was: They considered that some objects are too hard or thick for sound to vibrate; The third idea was that air is necessary for sound to travel; And the final idea was that, some objects absorb sound.

Propagation process. One type of incorrect answer in this question was that the dust particle would move away from the speaker when a sound was emitted, and two different explanations were identified. The first was that the dust particle would be pushed by a sound, and the second was that sound would not push the dust particle but the air in front of it. Both explanations seemed to be based on the participants' idea that sound has some shapes or forms. Another type of incorrect answer was that a sound would have no effect on the dust particle. All the three participants who presented this answer explained that they answered the question by guessing.

Propagation velocity. Only one type of incorrect answers was found, that was, the sound would go faster in the descent direction than in the ascent direction. Most of the participants explained this answer in terms of gravity. For example, they said, "The sound going in the descent direction would travel like falling down", or "Gravity would help the sound go down". These explanations obviously showed the tendency to attribute the property of weight to sound. Also, another explanation was based on their everyday experiences. One example is "Speakers at school or in the city are usually placed in a high place".

Amplitude and frequency of sound. For the questions of amplitude and frequency of sound, the typical incorrect answers were that when the sound body changes, both the volume and pitch would change. Take the answer in the question for string length for example, when the cord is lengthened, its volume would become louder and its pitch lower. Also several participants answered that the sound would change in neither volume nor pitch even when the sound body changed. Thus, there seemed a tendency to consider that the volume and pitch of sound were not independent but covariant. This tendency was more obvious in the drawing tasks. No specific pattern was found in the combination of the changes of volume and pitch.

Discussion

This study examined university literature students' knowledge of sound, by using the questions related to the Japanese study course. For the medium of sound, sound velocity, and amplitude and frequency, more than half of the participants gave scientifically correct answers in spite of the relatively few opportunities for them to take physics classes. However, most of them could not answer correctly the question on propagation, which is one of the most important properties of sound. These results suggest that university literature students could remember, to some extent, the contents of learning for sound except for how sound propagates.

According to the results of the question for sound medium, significantly more university literature students considered air, water and glass but not rubber as a medium of sound. Also, they answered that we could not hear sound or voices in outer space where there was no matter to act as a medium. In addition, about half of them did not consider iron, paper, wood or fabric as a medium. These results suggest the possibility that people did not directly understand the contents of learning, namely, almost all materials could be a sound medium, but rather they had other criteria that were generated based on their intuitive knowledge. According to the participants' explanations for their answers, three types of criteria were identified. The first type was that materials that were thick or hard could not be a medium because sound could not vibrate them. The second type, also related to the thickness or hardness, was that thick or hard materials could not be a medium because they did not have much space (air) for sound to travel. And the third type was that some materials such as rubber and wood have a sound-absorbing property, and thus they could not be a medium. The first and the third idea may suggest that they understand, to some extent, that sound velocity depends on the medium's states and characteristics such as elastic modulus and degree of density. Nevertheless, these two were considered as intuitive knowledge that sound is a kind of matter, as shown in the previous researches (Linder & Erickson, 1989; Mazens & Lautrey, 2003). The first idea seemed to involve the intuitive knowledge because sound as a kind of matter vibrates other materials. Also, the third idea seemed to reflect the intuitive knowledge because sound as a kind of matter is trapped in other materials. On the contrary, the second idea seemed to suggest a new type of intuitive knowledge that air must be necessary for sound propagation.

According to the questions for the propagation process, answers and explanations of the participants were similar to the results of the study by Wittman et al. (1999). Most of them provided either of the following two ideas. The first is that sound pushes other materials and the second is that sound pushes the air in front of the speaker but not other materials. In terms of material properties, these two ideas suggest that the property of substantiality is attributed to sound, as argued in Mazens and Lautrey (2003). However, three participants provided a different idea both from this intuitive knowledge and scientific knowledge. That is, there is no influence of sound on the other materials. This would suggest that they neither considered sound as a kind of material nor completely understood the property of longitudinal wave.

The results of the questions for sound velocity also revealed a tendency to consider sound as a kind of matter. Specifically, more than half of the university literature students attributed weight to sound. This result seemed inconsistent with the study of Mazens and Lautrey (2003), in which even most preschool children (71%) did not attribute weight to sound. These inconsistent findings may be due to a difference in task situation. According to Mazens and Lautrey (2003), the children listened to the noise of a clock and then the investigator asked the following question: "A child told me that the clock becomes a little bit lighter each time it makes a noise. Do you think she is right or wrong? Why?" In answering this question, it may be easy to imagine that they actually compare the weight of a clock in a direct way (e.g., compare the weight of a clock before and after it makes a noise). On the other hand, the situation given in the present study may invoke everyday settings such as speakers placed in higher position of schools or buildings. Indeed, several participants answered the question by quoting their everyday experiences.

Finally, the results of the question for amplitude and frequency of sound showed that relatively more participants remembered the scientifically correct relationship between changes in a sound body and changes in volume and pitch. However, about half of the participants drew incorrect sound waves in any situation, and their typical wave showed that when a sound body alters, both amplitude and frequency change. This result seemingly suggests that the participants draw such ad hoc waves, but this idea may be explained in terms of an equal-loudness contour, first measured by Fletcher and Munson (1933). Although amplitude and frequency of sound are treated independently in physics, volume and pitch are covariant in human perception, that is, when the frequency (pitch) alters, the volume is also considered to be changed even though the amplitude is invariant. And if the waves drawn by the participants reflect their perceptional experiences in everyday life, these results are likely to provide evidence that people use their everyday and intuitive knowledge when they remember the appropriate scientific knowledge.

In summary, this study identified eight types of intuitive knowledge of sound from the university literature students' explanations for four questions (see a-h in Table 2). Five are related to the intuitive knowledge that sound is a kind of matter (a, c, d, e and g). And two are related to sound propagation (b and f) and one to the relationship between volume and pitch (h). While some of the intuitive knowledge such as "substantiality and weight are attributed to sound" (Mazens & Lautrey, 2003) and "Sound pushed other materials" (Wittmann et al., 1999) were reconfirmed, this study adds three original types of intuitive knowledge. The first is that air is necessary for sound propagation (b); the second is that sound has no effect on sound propagation (f); and the third is that volume and pitch of sound are interactive with each other (h). The first and the third may show the obstructive influence of everyday experiences on understanding scientific knowledge of sound. However, the second is likely to suggest the partial understanding of sound propagation. Those who had this idea neither seemed to consider sound as kind of matter nor completely understood the property of longitudinal waves. Since only a few participants provided this idea in the present study, it is difficult to determine how many students are in this intermediate knowledge between intuition and science.

Table 2

Intuitive Knowledge Identified in Each Question

Question	Intuitive knowledge
Medium	a. Sound can not vibrate thick or hard materials.
	b. Sound needs some space (air) to travel.
	c. Sound is absorbed by some materials.
Propagation process	d. Sound pushes other materials.
	e. Sound pushes air but not the other materials.
	f. Sound has no effect on other materials.
Sound velocity	g. Sound goes down faster than it goes up.
Amplitude and frequency	h. Amplitude (volume) and frequency (pitch) are interactive with each other.

This study indicated what kind of intuitive knowledge potentially obstructs the university literature students' understandings of sound, using the questions based on the contents of learning that had been taught in junior high school science classes. However, it is still unclear whether these types of intuitive knowledge actually hinder students from learning sound. Thus, it is necessary to examine the on-line process of understanding of sound in the real classroom. Moreover, it is possible that the intuitive knowledge identified here is acquired from everyday experiences after formal education. Thus, it is also necessary to include junior high school students and compare their understanding before and after the science classes of sound.

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Appendix

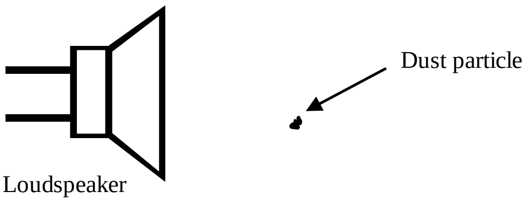
Question for medium of sound

(1) Circle every item that you think can be a medium of sound, and explain why you think so.

{air/water/wood/rubber/glass/paper/iron/fabric}

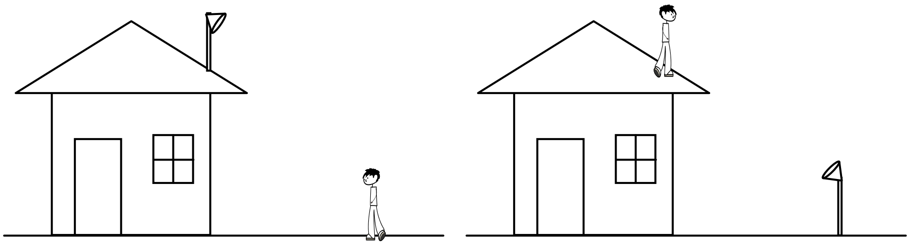
(2) Do you think that it is possible to hear voices or noises in outer space? Why?

Question for propagation process



A dust particle is hanging in the air in front of a loudspeaker. When a sound with constant volume and pitch is emitted from the speaker, what do you think will happen to the dust particle, and why? Note that there is no wind.

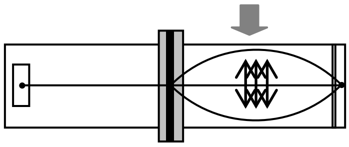
Question for sound velocity



In the left picture, a boy is standing on the ground and a loudspeaker is put on the roof of the house. On the contrary, in the right picture, a boy is standing on the roof and a loudspeaker is put on the ground. When a sound with constant volume and pitch is emitted from the loudspeaker to the boy, in which picture the sound can reach faster to the boy, and why? Note that it is fine and quiet day and there is no wind.

Question for amplitude and frequency

Here is a monochord, a musical instrument with only one string.



(1) When the power pluck becomes stronger, how will its sound change?
(2) When the length of the string becomes longer, how will its sound change?
(3) When the tension of the string becomes tighter, how will its sound change?
(4) When the size of the string becomes thicker, how will its sound change?
Grid sheet: the gray wave represents the original sound.