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The Auditory Velocity Illusion Caused by Sounds of Different Intensities

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Most of the numerous studies on velocity illusion have focused on the visual velocity illusion, with few studies focusing on the auditory velocity illusion. As a step toward filling this lacuna, the present study concentrated on the auditory velocity illusion through the use of pendulum motion. We attempted to replicate the visual velocity illusion named Brown's law (Brown, 1931) as an auditory velocity illusion. It is highly likely that an auditory velocity illusion occurs on account of changes in the sound pressure level (SPL), since we easily tend to match object size with loudness (Lipscomb & Kim, 2004). Thus, we examined whether or not the SPL changes of a moving object would cause the auditory velocity illusion. The results clearly indicated that the velocity of a moving object was perceived as faster when the object emitted a louder sound.

Key words: auditory velocity illusion, Brown's law, sound intensity

Introduction

In order to avoid traffic accidents and other dangerous collisions, we need to perceived velocity in the appropriate manner. Consequently, many studies focusing on velocity illusion have conducted in the past. However, the mechanism of a velocity illusion has not been sufficiently deal with as yet. The theory of velocity perception is classified into two types of theories (see Strybel, Span, & Witty, 1998, for a review). The first type assumes that velocity is a primary sensation and not inferred from distance and time estimates. The second one holds that velocity is perceived indirectly from the estimated traveling distance and duration of movement. The former theory predicts that velocity discrimination should be more accurate when the velocity is perceived directly than when it is predicted on the basis of the measures of distance and time. Moreover, velocity adaptation phenomena are considered as supportive of the primary velocity view (Lappin, Bell, Harm, & Kottas, 1975). In fact, velocity-tuned cells exist in the monkey (Maunsell & Van Essen, 1983). However, the former theory cannot explain the velocity illusion phenomenon (Strybel et al., 1998). If the velocity is perceived directly, the velocities should be perceived as equivalent when two objects' velocities are physically same,

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which is not found to be the case in many instances. However, if the perception of traveling distance and motion duration relates to velocity perception, the mistakes in distance or duration estimation could cause velocity illusions.

One of the famous visual velocity illusions is found in Brown's law (Brown, 1931). Brown's law denotes the phenomenon in which the apparent velocity of a smaller object is perceived as faster in comparison to that of a larger object. Also, the apparent velocity of an object of lower luminance is reported to be perceived as faster than that of an object of higher luminace (Hammett, Champion, Thompson, & Morland, 2007; Vaziri-Pashkam, & Cavanagh, 2008). Moreover, the contrast in the visual stimuli is another factor causing the visual velocity illusion (Thompson, 1982; Thompson, Brooks, & Hammett, 2006). A number of studies similar to the above have been conducted on the visual velocity illusion.

In contrast, studies on the auditory velocity illusion have been few and far between. Strybel and his co-workers (1998) conducted one of such few studies. They investigated the auditory apparent motion (AAM) and proved that AAM velocity was perceived as faster when the burst duration and stimulus onset asynchrony (SOA) were shorter and the distance between the sound sources was longer.

However, thus far, there has been no study examining auditory smooth motion. Therefore, we examined auditory smooth motion by using a pendulum. Taking Brown's law and the fact that visual object size tends to be easily matched with auditory loudness (Lipscomb & Kim, 2004) into consideration, it is plausible that the given object's motion at various sound pressure levels (SPLs) would induce the auditory velocity illusion. In the present study, we examined whether or not the auditory velocity illusion could be induced by manipulating the sound intensity of the object in pendulum motion with the if we observed the same effect as in Brown's law, we would hypothesize that the an object's velocity is perceived as faster when its sound intensity is lower.

Method

Participants

A group of 8 observers (3 females and 5 males) participated in this experiment. They were all normal hearing and were naïve as to the purpose of this experiment.

Apparatus

A pendulum stimulus was constructed and used in this experiment (see Figure 1). The pendulum was attached to a speaker (HK206, DELL). The participants sat at a distance of 200 cm in front of the pendulum and heard the presented stimuli. The velocity of the pendulum's motion was changed by manipulating the length between the fulcrum and the speaker. The velocity was faster when the length was shorter, and was slower when the length was longer. We varied the position of the speaker, holding it at the same height from the floor whenever we manipulated the velocity. The participants' head movement was restrained

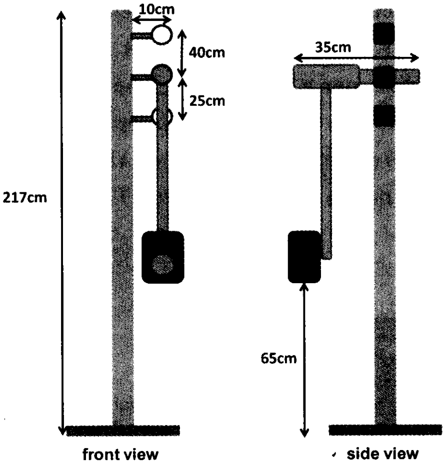

Figure 1. The experimental apparatus used in the present experiment. The apparatus comprised plastic pipes and fasteners attached to a speaker. The object's velocity was manipulated by changing the length between the fulcrum and the speaker.

through the use of a chin-rest device. Moreover, the participants made to wear eye-masks to prevent them from observing the speaker's motion. The generation and presentation of the stimuli was controlled by a custom-made program written by using a Matlab (The Mathworks, Inc.), Cogent 2000 toolbox (www.vislab.ucl.ac.uk/cogent.php) and a PC (PRECISION T5400, DELL; OS: WindowsXP, Microsoft). The experiment was conducted in a completely dark room, and the background noise level was set at 43 dB.

Stimuli

The stimuli comprised the white noise emanating from a moving pendulum's motion. The SPL of the standard stimulus was 70 dB and the velocity was 10 deg/s. The comparison stimuli comprised 9 condition types (3 SPLs × 3 velocities). The SPL levels were 50 dB (low), 70 dB (medium), and 90 dB (loud). The three velocity levels were 8 deg/s (slow), 10 deg/s (medium), and 12 deg/s (fast). The moving distance of the stimuli on the pendulum was about 4.5 deg in horizontal width. There were two movement-direction patterns (rightward and leftward).

Procedure

Each stimulus was presented by swinging the pendulum. Each trial was composed of one standard and one comparison stimulus. The participants were instructed to perform a two-alternative forced choice (2AFC) task . If they perceived the former stimulus as faster, they verbally responded with "former," whereas if they perceived the latter stimulus as faster, they responded with "latter." A 3 × 3 factorial design was used, with SPL and velocity condition as within-subject factors. The SPL condition comprised three levels (50 dB, 70 dB, and 90 dB), as did the velocity condition (8 deg/s, 10 deg/s, and 12 deg/s). In total, the participants performed 180 experimental trials (20 trials per a condition). The total trials were divided into two sections on the basis of movement direction, and the order of the sections was counterbalanced across the participants. Furthermore, the position of the comparison stimulus (former or latter) was also counterbalanced across the participants. The flow of the single trial is depicted in Figure 2.

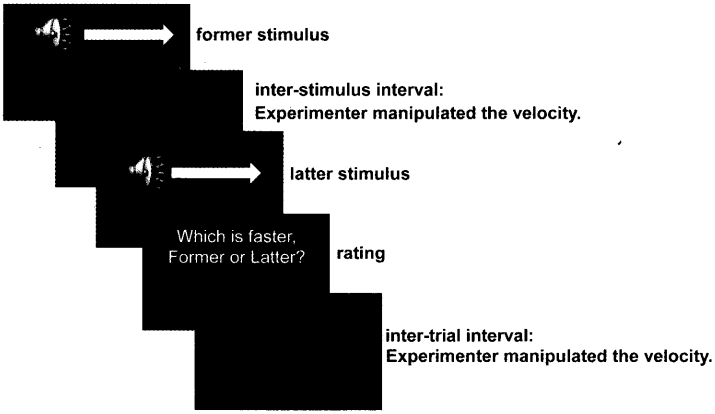

Figure 2. Schematic representation of the procedure.

Results

We calculated the rate of the comparison stimuli that were chosen as "faster." The results are depicted in Figure 3. Furthermore, an two-way analysis of variance (ANOVA) with SPL and velocity as the with-in subject factors was conducted after the angular transformation of the data. The main effect of SPL was significant $F\ (2, 14) = 58.11, p < .001$, indicating a change in the participants' performance as a function of SPL. Multiple comparisons of the main effect of SPL (Ryan's method) showed significant differences among the three SPL conditions, a fact that indicated that the pendulum motion of the louder sound was perceived as having faster velocity. Also, the main effect of velocity was significant $F\ (2, 14) = 17.98$, $p < .001$. Multiple comparisons of the main effect of velocity showed significant differences among the three velocities, which indicated the participants' ability to appreciate a difference among velocities. Furthermore, the interaction between SPL and velocity was also significant $F\ (4, 28) = 3.22, p < .05$. Multiple comparisons of the interaction between SPL and velocity proved that the difference between 70 dB and 90 dB when the velocity was 12 deg/s and between 8 deg/s and 10 deg/sec when the SPL was 50 dB was not significant.

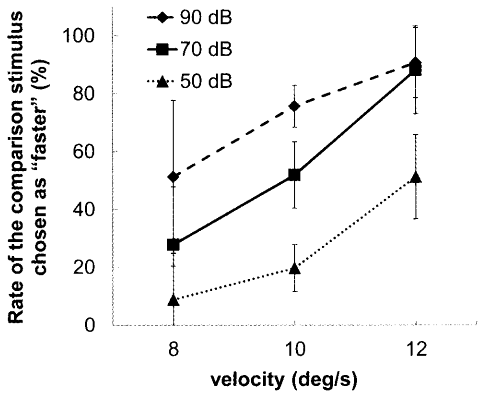

Figure 3. The horizontal axis indicates the presented velocities and vertical axis indicates the mean rate of the comparison stimulus being chosen as "faster." The error bar represents the standard deviation ($n = 8$).

Furthermore, we measured the response bias by applying the signal detection theory. To measure the response bias, we calculated the position bias logβ(i.e., the tendency of the participants to prefer former or latter in their responses). As an analysis target, we regarded the trials of 8 and 10 deg/s to determine which stimulus velocity differed between the standard and comparison stimuli. Since the task assigned to the participants was to identify the faster stimulus, we regarded the faster velocity of the presented stimuli as signal and the slower velocity stimulus as noise. Logβ was calculated using $Z(P_{c<SN>})$ (z-score of correct rate when signal was presented as the former stimulus) and $Z(P_{c<NS>})$ (z-score of correct rate when noise was presented as the former stimulus). The formula to calculate logβ is indicated below.

$$\log\beta = \frac{1}{2}\left(Z^2\left(P_{c(NS)}\right) - Z^2\left(P_{c(SN)}\right)\right)$$

When log$\beta > 0$, it is indicated that the participants have a bias toward selecting the latter stimulus, whereas when log$\beta < 0$, it is indicated that the participants have a bias toward selecting the former stimulus. Using the above formula, we calculated the position bias of each SPL condition. The results are depicted in Figure 4. Furthermore, we conducted a comparison of the position bias between 70 dB and 50/90dB, separating the position of comparison stimulus by an one-way ANOVA. As a result, the difference between 70 dB and 50 dB was found to be significant $F(1, 7) = 31.74$, $p < .001$ when the position of comparison stimulus was the latter. However, the position bias of other conditions was not significant. Therefore, this result indicated that the participants did not have a position bias other than 50 dB when the position of the comparison stimulus was the latter.

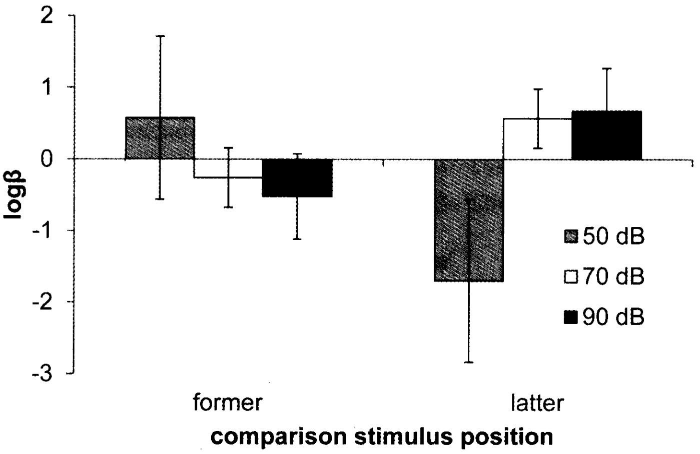

Figure 4. The horizontal axis indicates the position of the comparison stimulus and the vertical axis indicates log*β*. "Former" indicates that the comparison stimulus was presented before the standard stimulus, and "latter" indicates that the comparison stimulus was presented after the standard stimulus. The error bar represents the standard deviation ($n = 8$).

Discussion

The conducted experiment clearly indicated that the auditory velocity illusion could be induced by manipulating the sound intensity of the pendulum's motion. In clearer terms, the auditory velocity of a moving object was perceived as faster when the sound emitted by the object was louder. In contrast, the auditory velocity was perceived as slower when the sound intensity was lower. Since the observed effect of the participants' response bias was almost negligible, this effect was assumed to occur at a perceptual level. Therefore, it can be concluded that the sound intensity of the pendulum's motion itself increases the perceived velocity. Moreover, the results of the multiple comparisons indicated some characteristics of this auditory velocity illusion. The difference between 8 deg/s and 10 deg/s was not significant when SPL was 50 dB. This result demonstrates that the velocity of 10 deg/s was perceived as slower than that of 8 deg/s when the SPL was 50 dB. This suggests the presence of the speed-down effect of lower sound intensity. Also, the range at which this auditory velocity illusion occurred was limited in the particular conditions. The difference between 70 dB and 90 dB was not significant when the velocity was 12 deg/s. This result indicated that the velocity of the 70 dB SPL was perceived to be equal to that of the 90 dB SPL when the velocity was 12 deg/s, thus indicating that the 90 dB SPL did not exert the speed-up effect when the velocity was 12 deg/s. In order words, the speed-up effect due to the 90 dB sound level occurred only when velocity was under 12 deg/s.

We hypothesized that the velocity was perceived as faster when the sound intensity was lower. As a lower auditory level easily matches a small-size object (Lipscomb & Kim, 2004), it can be inferred that the velocity of a low intensity sound is perceived as faster, since we tend to perceive that a smaller object moves faster. However, the present experiment's results refuted this hypothesis. The velocity of an object emitted sound of lower intensity was perceived as slower, whereas that of an object emitted sound of higher intensity was perceived as faster. Therefore, the results contradicted the initial hypothesis. There is a possibility that the present results might have been obtained due to the change in the estimated traveling distance of moving sound, instead of the estimated size of the auditory moving object, since auditory modality is generally inferior in spatial resolution. It is plausible that the traveling distance was misperceived due to the changing sound intensity. In other words, a moving sound of higher intensity might result in a longer perceived traveling distance. If the velocity is perceived indirectly from the estimated traveling distance and duration of movement (Strybel et al., 1998), the velocity is perceived as faster when the perceived traveling distance is longer under the same perceived duration of movement.

The results of the present study indicate that the intensity of the moving sound induces velocity illusion. In other words, when we perceive the velocity of an object that moves around a blind corner, we misperceive the velocity from the difference in the sound intensity when the actual velocity is the same.

Finally, we describe an important implication of the present study. In recent times, there has been much effort to introduce a number of next generational eco-cars. Most eco-cars emit a lower sound than traditional cars. Therefore, it can be predicted from the present results that the velocity of eco-cars would be generally perceived as slower than their actual velocity. This fact would result eco-cars posing a higher accident risk than traditional cars. Therefore, the auditory velocity illusion we have brought to light has a very significant important and is worth being investigated further in future researches.

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