Modification of velocity perception by loud sounds

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Auditory stimuli are known to alter visual perception. However, the effects of such stimuli on velocity perception have not yet been examined. A well-known velocity illusion related to object size is described by Brown’s law. We can easily match object size with sound intensity. Therefore, this study examined the potential modification of velocity perception by auditory stimuli at different sound pressure levels (SPLs). The results showed that the perceived velocity, particularly when the object size was small, diminished with a high SPL auditory stimulus. We assume two interpretations of this result. First, high intensity sounds can modify the perceived object size and alter the perceived velocity by replicating Brown’s law since large objects tend to match well with high SPL sounds. Second, previous studies indicated that stimuli with strong intensities seem to have been presented for longer durations. Thus, stimulus duration may be perceived as longer when higher SPL sounds are presented simultaneously, which may cause the velocity to be perceived as being slower.

Key words: audio-visual interaction, velocity perception, visual illusion, information reliability hypothesis

Introduction

Velocity perception is one of the important capacities for us in daily life. We need to perceive velocity accurately in order to dodge or catch moving objects (e.g., a rock or ball). In addition, this ability is important for avoiding collisions in traffic. The mechanism of velocity perception has not yet been elucidated thoroughly. Previous studies have advocated two theories of velocity perception (see Strybel, Span, & Witty, 1998 for a review). The first assumes that velocity perception is a primary sensation and is not inferred from distance and time estimates. The second holds that velocity is perceived indirectly from estimations of traveling distance and duration of movement. The former theory predicts that velocity discrimination should be more accurate than what would be predicted from measures of distance and time discrimination. Moreover, velocity adaptation phenomena are said to support the primary velocity view (Lappin, Bell, Harm, & Kottas, 1975). In fact, velocity-tuned cells exist in monkeys (Maunsell & Van Essen, 1983). However, the former theory cannot explain velocity illusions (Strybel et al., 1998). If velocity is perceived directly, equal velocities should always be perceived as being equivalent, but they are not. However, if traveling distance and duration of movement are related to velocity perception, errors in these estimates produce cause velocity illusions. Therefore, we assume that the latter theory is more valid with respect to velocity illusions.

Many velocity illusions have been examined in previous studies based on the latter theory. For example, the apparent velocity is perceived to be faster at lower luminance (Hammett, Champion, Thompson, & Morland, 2007; Vaziri-Pashkam & Cavanagh, 2008). Contrast is another important factor that causes visual velocity illusions (Thompson, 1982; Thompson, Brooks, & Hammett, 2006). Moreover, object size greatly affects velocity perception.

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Brown (1931) suggested that the apparent velocity is perceived to be faster when the object size is smaller. By contrast, apparent velocity is perceived to be slower when the object size is larger. This velocity illusion is called Brown's law.

Until now, many studies on velocity illusion have examined only the visual modality. However, auditory stimuli are known to alter visual perception through audio-visual interaction (Driver & Spence, 2000; Shimojo & Shams, 2001). Typical phenomena of audio-visual interaction are the McGurk effect (McGurk & MacDonald, 1976) and ventriloquism effect (Jack & Thurlow, 1973). These studies indicate that visual modality is superior to other modalities (visual dominance). However, Sekuler, Sekuler, and Lau (1997) and Shams, Kamitani, and Shimojo (2000) showed that the auditory modality can also dominate the visual modality.

For velocity perception, Manabe and Riquimaroux (2000) reported that apparent motion is perceived to be faster when shorter auditory stimuli are presented in the blank. Thus, visual velocity tends to be altered by auditory stimuli. However, this study did not examine smooth motions. In real-life situations, it may be quite rare for sounds to be emitted only during apparent motion's blanks, which corresponds to the experimental conditions examined by them. Therefore, we tried to investigate the effects of sounds on the velocity perception of real objects moving with sound.

Another factor not examined in previous studies is the intensity of auditory stimuli. Lipscomb and Kim (2004) showed that we can easily match sound intensity with object size; that is, to match high intensity sounds with large objects and low intensity sounds with small objects. As described above, differences in object size alter perceived velocity (Brown's law). Therefore, it is highly likely that adding auditory stimuli of different sound intensities differentially modifies perceived object size.

In short, we investigated audio-visual interactions in velocity perception. We combined different object sizes with different sound pressure levels (SPLs) and examined whether the perceived visual velocity of the objects could be modified. We hypothesized that adding a high SPL auditory stimulus would make perceived velocity slower, whereas adding a low SPL auditory stimulus would make it faster. In order to examine a more realistic smooth motion, we used the motion of a pendulum in this study.

**Method**

**Participants**

A group of 8 observers (4 females and 4 males) participated in this experiment. All had normal vision and audition, and all were naive 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) and 5-mm light-emitting diodes (LEDs). White LEDs (LD504W 3CD2B02P, Linkman) were used for circular visual stimuli and a red LED (LFTLED-R501, Linkman) was used as the fixation point. The luminance of each LED was 15 cd (white) or 0.5 cd (red). For the visual stimulus, white LEDs were arranged in triple rings. There were 36 white LEDs in total (8, 12, and 16 for the small, medium, and large circles, respectively). The fixation light was attached at the height of the participant's eye, and the visual stimuli were attached just above the speaker. The distance from the fixation point to the center of the circles was 4.37 deg. An audio interface (ProFire Lightbridge, M-AUDIO), signal synchronism device (Nanosynchs HD, Rosendahl), AD/DA converter (Ultragain Pro-8 Digital ADA8000, Behringer) and amplifier (RSDA 202, Rasteme systems Co., Ltd.) were used to turn on the device (see Figure 2). Participants sat 200 cm in front of the pendulum. Head movements were restrained by a chin rest device. The generation and presentation of stimuli were controlled by a custom-made program written using Matlab (The Mathworks, Inc.), a Cogent Graphics and 2000 toolbox (www.vislab.ucl.ac.uk/cogent.php), and a PC (PRECISION T5400, DELL; WindowsXP, Microsoft). The visual and auditory stimuli were controlled to appear when the pendulum moved halfway along its trajectory (4.5 deg). The participants were instructed to judge the maximum velocity of pendulum motion.
Figure 1. (a) Experimental apparatus used in the present experiment and (b) visual stimuli's size. The apparatus was made from plastic pipes and fasteners, an attached speaker, and two types of LEDs. Velocity was manipulated by changing the length between the fulcrum and speaker.

Figure 2. Electric diagram of the apparatus.

The experiment was conducted in a completely dark room, and the background noise level was 43 dB (A).

Stimuli

The visual stimuli were the pendulum motions of circular LEDs, and auditory stimuli were white noises of two SPLs. The standard stimulus was a visual stimulus without white noise. The internal circumference of the standard stimulus was 0.86 deg, and the external circumference was 1.15 deg. The comparison stimuli were of 6 types (2 object sizes × 3 auditory conditions). The 2 object sizes were small and large. The internal and external circumferences of the small stimulus were 0.43 deg and 0.72 deg, and those of the large stimulus were 1.29 deg and 1.58 deg, respectively. The 3 auditory conditions were No-Sound, which indicates that the auditory stimulus was not presented; 50 dB, which indicates that 50 dB (A) white noise was presented simultaneously with visual stimuli; and 90 dB, which indicates that 90 dB (A) white noise was presented simultaneously with visual stimuli. According to the study conducted by Andersen, Tiippana, and Sams (2004), we controlled the information reliability of auditory stimuli by manipulating the intensities of sounds. All stimulus velocities were 10 deg/s. In catch trials, the visual stimulus (size was same as the standard stimulus with a velocity of 8 or 12 deg/s) was presented without white noise. There were two movement directions, rightward and leftward.

Procedure

Each stimulus was presented by swinging the pendulum. Each trial was composed of one standard stimulus and one comparison stimulus. Participants were instructed to perform a two-alternative forced choice task (2AFC). If the former stimulus was perceived to be faster, they verbally responded "former," whereas if the latter stimulus was perceived to be faster, they responded "latter." A 2×3 factorial design was used with the object size and auditory condition as within-subject factors. 24 trials (20% of experimental trials) were added as catch trials of one of the 2 velocity levels. In total, each participant performed 144 trials, i.e., 120 experimental trials (20 repetitions per condition) and 24 catch trials (12 repetitions per condition). The total number of trials was divided into two sections depending on the direction of movement, and the order of the sections was counterbalanced across participants. The order of the comparison stimulus (former or latter) was also counterbalanced across participants. The flow of a single trial is depicted in Figure 3. The participants were not allowed to look at the apparatus during the inter-stimulus interval (ISI) and inter-trial
Figure 3. Schematic representation of the procedure. Black rectangles indicate the periods during which participants wore an eye-mask.

![Figure 3](image.png)

Figure 4. Horizontal axis indicates auditory conditions, and vertical axis indicates the mean rate of the comparison stimulus chosen as "faster." The error bar represents the standard deviation (n=8).

![Figure 4](image.png)

Results

The results of the catch trials were excluded from the analysis. We calculated the rate of the comparison stimulus chosen as "faster." The results are depicted in Figure 4. Furthermore, an analysis of variance (ANOVA) with object size and auditory condition as within-subject factors was conducted after angular transformation of data. The main effect of the object size was significant $F(1, 7)=6.00, p<.05$, indicating that the perceived velocity varies as a function of object size. In addition, the simple main effect of size in the No-Sound condition was significant $F(1, 21)=9.37, p<.01$, indicating that Brown's law was replicated in this experiment. Also, the main effect of the auditory condition was marginally significant $F(2, 14)=3.59, p=.055$. Furthermore, the interaction between the object size and auditory condition was significant $F(2, 14)=4.03, p<.05$. Multiple comparisons of the interaction between object size and auditory condition (Ryan's method) revealed that the differences between No-Sound/50 dB and 90 dB conditions were significant when the object size was small, indicating that the velocity seemed slower when the 90 dB (A) white noise was added when the object size was small. In contrast, the simple main effect was not significant when the object size was large.

Discussion

In this study, we examined the effect of audio-visual interactions on velocity perception by combining objects of different sizes with different SPLs. The results indicated that a high SPL auditory stimulus tended to cause the perceived velocity to be slower. In particular, this effect was found to be much stronger when the object size was small. Furthermore, low SPL sounds did not affect the visual perception of velocity. In a previous study, the velocity of apparent motion of an object was perceived as
higher when a shorter noise burst was presented in the blank (Manabe & Riquimaroux, 2000). The results differ from those of the present study, which indicated that the high intensity sound slowed the perceived velocity of the object in real motion. In the case of apparent motion, the inserted sound might not be perceptually bound to the object, whereas the presented sound might be one of perceptual attributes ascribable to the moving object in the present study. Therefore, it can be assumed that the different perceptual integration processes might be involved in the two cases.

There are two plausible explanations for the present results. The first assumes that high intensity auditory stimulus may alter the perceived visual object's size depending on the multi-modal information reliability. According to Lipscomb and Kim (2004), high intensity sounds tend to match with large objects. In addition, the information reliability hypothesis states that the modality of high-reliability information is superior to that of low-reliability information (Wada, Kitagawa, & Noguchi, 2003). We manipulated the information reliability of an auditory stimulus by the sound intensities in this study. Therefore, it is plausible that an object might be perceived to be larger when accompanied by a louder SPL sound, which has high-reliability information relative to visual stimulus, and thus the perceived velocity is slower due to Brown's law. On the other hand, the information reliability of low SPL sounds is low relative to visual stimulus, and thus it does not affect the perceived visual velocity.

The second explanation assumes that the duration of visual stimuli may be modulated by auditory stimuli corresponding to the stimuli's intensity. In the previous studies, the duration of visual stimuli was perceived as longer when these stimuli's intensity was stronger; that is, the visual size is larger (e.g., Ono & Kawahara, 2007; Thomas & Cantor, 1976; Xuan, Zhang, He, & Chen, 2007). If the same phenomenon occurs by adding auditory stimuli, the duration of visual stimuli is perceived as longer when higher SPL sounds are presented simultaneously. According to the theory that velocity is perceived indirectly from the estimated traveling distance and duration of movement, the velocity is perceived as slower when the perceived duration becomes longer. The fact that low SPL sounds did not alter the perceived visual velocity can be accounted for by the shortage of the auditory stimuli's intensity for modulating the perceived duration.

However, the effect of the modification of perceived velocity was found to be much reduced when large objects were accompanied by high SPL sounds. The perceived velocity was almost identical among the auditory conditions. This result might indicate that the speed-down effect of Brown's law is powerful enough that it may produce a sort of ceiling effect for the perceived velocity, making the influence of sound stimuli relatively small or negligible. These arguments, including the validity testing of the two types of explanations, must be clarified via further cross-modal psychophysical investigation.

We obtained interesting knowledge on audio-visual interaction with velocity perception from this study. In order to evaluate the validity of the discussion based on the two assumptions stated above, further psychophysical experiments with an increased number of stimulus parameters that affect the information reliability and (or) stimuli intensity over a wider range are required.

References


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