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# Visual motion disambiguation by a subliminal sound

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## Abstract

There is growing interest in the effect of sound on visual motion perception. One model involves the illusion created when two identical objects moving towards each other on a two-dimensional visual display can be seen to either bounce off or stream through each other. Previous studies show that the large bias normally seen toward the streaming percept can be modulated by the presentation of an auditory event at the moment of coincidence. However, no reports to date provide sufficient evidence to indicate whether the sound bounce-inducing effect is due to a perceptual binding process or merely to an explicit inference resulting from the transient auditory stimulus resembling a physical collision of two objects. In the present study, we used a novel experimental design in which a subliminal sound was presented either 150 ms before, at, or 150 ms after the moment of coincidence of two disks moving towards each other. The results showed that there was an increased perception of bouncing (rather than streaming) when the subliminal sound was presented at or 150 ms after the moment of coincidence compared to when no sound was presented. These findings provide the first empirical demonstration that activation of the human auditory system without reaching consciousness affects the perception of an ambiguous visual motion display.

Keywords: Subliminal sound; Visual motion; Cross-modal; Audiovisual integration

## 1. Introduction

The ability to respond to external stimuli is enhanced by binding signals from multiple sensory modalities. Studies of perceptual illusions such as the ventriloquist and the McGurk effect in which conflicting multisensory information is erroneously perceived to be bound together suggest that cross-modal binding is a fast and pre-attentive process (Driver, 1996; McGurk & MacDonald, 1976; Sekuler, Sekuler, & Lau, 1997). However, there has recently been much debate regarding cross-modal illusion perception, and the confounding influence of response bias and other decision factors (Bertelson & de Gelder, 2004). The “bouncing–streaming” illusion involves two objects moving towards one another, reaching the same position, and then moving apart. This motion can be perceived as the objects moving in either a constant trajectory (i.e., streaming through one another) or a reverse trajectory (i.e., bouncing off one another as if following a collision). The possible subjective and interpretative effects of the sound influence in the bouncing streaming visual illusion (Sekuler et al., 1997) have recently been addressed (Sanabria, Correa, Lupianez, & Spence,

2004). It has been shown (Sekuler et al., 1997) that the perception of bouncing can be increased by a sound at the moment of contact, suggesting that the sensory information perceived in one modality (audition) can modulate the perception of events occurring in another modality (i.e., ambiguous visual motion perception). However, this cross-modal effect may simply reflect a cognitive bias whereby the sound resembles the transient auditory stimulus produced by a physical collision of two objects, causing subjects to infer the reversal of motion direction from the presence of this factor generally associated with bouncing in the physical world.

Cognitive biases linked to subjective reports in the sound bounce-inducing effect have recently been ruled out by an elegant paradigm (Sanabria et al., 2004) in which the point of coincidence of two moving disks was hidden behind an occluder. When emerging from behind the occluder, the disks (one red, the other blue) could either follow the same trajectory (streaming) or else move in the opposite direction (bouncing). Participants made speeded discrimination responses regarding the side from which one of the disks emerged from behind the occluder. Participants responded more rapidly on streaming trials when no sound was presented compared to 'streaming with sound' trials, and also responded more rapidly on bouncing trials when sound was presented at the moment of coincidence compared to 'bouncing without sound' trials. Although this paradigm provides an implicit/objective behavioral measure of the sound bounce-inducing effect, it does not rule out interpretative response biases whereby subjects explicitly infer the reversal of motion direction from the presence of the sound even when the collision is not visible.

The present study used a novel method to overcome the issue of interpretative bias in the sound bounce-induced effect. The approach involved stimulating the auditory system without the subject being conscious of the stimulation. This was achieved by presenting a subliminal sound either 150 ms before, at, or 150 ms after the moment of coincidence of two disks. An increase in the proportion of "bounce" responses in the presence of a subliminal sound would be inconsistent with a cognitive bias regarding the bounce-inducing effect.

## **2. Experiment 1**

### **2.1. Methods**

#### **2.1.1. Subjects**

The study involved 12 subjects (6 females and 6 males) who were paid volunteers and were unaware of the purpose of the experiment. Importantly, the subjects were not aware of the presence of a subliminal sound during the visual motion experiment. The experiment took approximately 20 min to complete and was performed in accordance with the ethical standards stated in the 1964 Declaration of Helsinki. Informed consent was obtained after the nature and possible consequences of the studies were explained. Audiograms (1702 Audiometer Grason-Stadler\_) in the 250–8000 Hz range were performed, and all subjects exhibited normal hearing.

### 2.1.2. Materials

Visual stimuli were presented on a 15-in. VGA computer monitor in a dimly illuminated room. Sounds were presented through head phones. The synchrony between the auditory and visual stimuli was physically verified by measuring the output signal of the computer soundboard and the photometer signal at the point of coincidence of the two disks. Inter-stimuli time intervals were then adjusted with respect to the soundboard and computer screen asynchrony.

### 2.1.3. Procedure

2.1.3.1. Auditory threshold. Prior to the "visual motion" experiment, an auditory detection threshold for a brief sound was assessed for each subject. Through head phones, the subjects heard a white noise (20–20,000 Hz) of 2 s in duration and 65 dB SPL. A pure tone (500 Hz) of 10 ms in duration was presented 400, 800 or 1200 ms after the beginning of the white noise. Subjects performed a forced-choice detection task: they were asked to press a response button when they heard the 500 Hz signal, and a second button when they did not hear the signal during the presentation of the white noise. Detection thresholds were assessed using the method of constant stimuli. Eleven signal sound levels were presented 20 times, each time in a random order. A cumulative normal distribution was fitted to the data from each subject using probit analysis (Finney, 1962). The mean of this function (the 50% point) represented the sound level yielding maximum uncertainty and was used in the visual motion experiment as the subliminal stimulus.

### 2.1.3.2. Visual motion.

Subjects sat 50 cm from the computer screen. In each trial, two white disks (diameter: 0.6°, luminance: 90 cd m<sup>-2</sup>) appeared on opposite sides of a dark computer screen. The disks were presented symmetrically from one of three possible elevations on the computer screen (at an eccentricity of 8.8°): the disks appeared at the top of the screen when moving diagonally from top-to-bottom; at the middle when moving on a horizontal trajectory; and at the bottom when moving diagonally from bottom-to-top. In the vertical trajectory condition the disks appeared, respectively, at the top and bottom of the screen (at an eccentricity of 8.8°). The disks moved at 8.8 deg s<sup>-1</sup>, and a white noise (20–20,000 Hz) of 2 s in duration and 65 dB SPL was simultaneously delivered through the head phones. A subliminal auditory stimulus was presented 150 ms before, at or 150 ms after the moment of coincidence of the two disks. In one quarter of the trials, no subliminal sound was presented with the white noise. Each trajectory-sound combination was presented six times in random order. The trial ended when each disk had reached the other's starting position, both disks disappeared from view and the white noise stopped (i.e., 2 s). Subjects indicated whether the disks appeared to stream through or bounce off one another by pressing one of two possible buttons. No response time constraint was imposed upon the subjects. After the experiment, subjects were asked whether they had heard a sound similar

to the one used during the threshold experiment. That debriefing revealed that no subject had heard the subliminal sound.

## 2.2. Results

The presentation of a subliminal sound was found to enhance the perception of bouncing (Fig. 1) ( $F[3,33] = 5.44, p < .01$ ). When a subliminal sound was presented at the moment of coincidence of the two disks

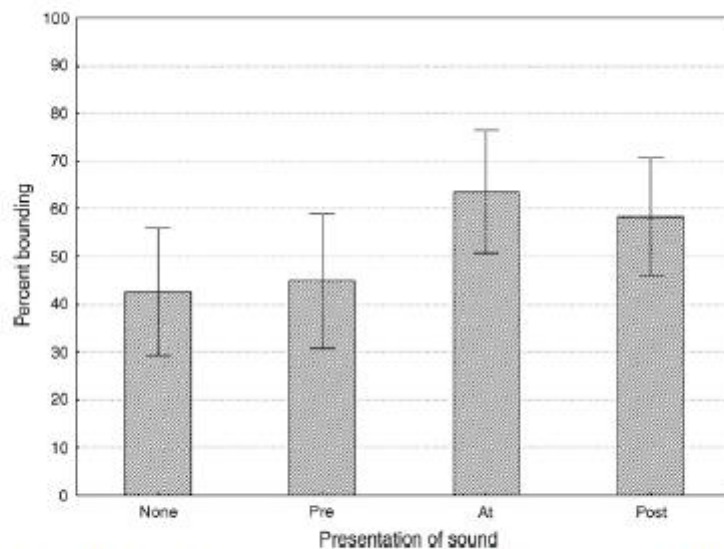


Fig. 1. Mean percentage ( $\pm$ SEM) of reports of stimulus bouncing. Motion was accompanied by a brief sound 150 ms before (Pre) or after (Post) the disk coincidence, or at the moment of coincidence. A control condition presented no sound (none).

or 150 ms later, the bouncing perception proportion was 63.54% and 58.33%, respectively, compared to 42.71% for the 'no sound' condition ( $p < .05$ , Newman-Keuls a posteriori test). The percentages at, the moment of coincidence or 150 ms after, did not significantly differ from each other. The bouncing response percent did not significantly differ from the no sound condition when the sound was presented 150 ms before coincidence. Although subjects declared they had not heard the 500 Hz target sound embedded in the white noise during the visual task, it might be argued that at a 50% detection threshold, the sound might have been heard in some trials, and that this may explain the observations. Therefore, a second experiment was performed in which subjects reported after each trial whether or not they had heard the 500 Hz target sound. We hypothesized that if the percentage of bouncing responses remains enhanced in trials where subjects have explicitly declared not having heard the sound, the observed visual perception effect would most likely be due to activation of the auditory system by subliminal sounds.

## 3. Experiment 2

### 3.1. Subjects

Twelve subjects (7 females, 5 males) who had not participated in Experiment 1 were enrolled for Experiment 2.

### 3.2. Procedure

The same materials were used as in Experiment 1, except that sounds were played through 2 loud-speakers placed on each side of the computer monitor in order to maximize multisensory integration. Prior to the experiment, subjects were assessed for auditory detection thresholds for a brief sound using the same procedure as described in Experiment 1. The visual motion experiment used three 500 Hz sound intensities: (a) the intensity which yielded 100% detection, (b) the intensity which yielded 75% detection, and (c) the intensity which yielded 50% detection. In a fourth condition the target sound was absent. Each of the four conditions was randomly selected and presented 24 times to result in a total of 96 trials. Once subjects had responded to the “Bounce or Stream” question by pressing one of two buttons, they reported on whether they had heard the 500 Hz target sound or not by pressing one of two other buttons.

### 3.3. Results

The mean percentage of sound detection as a function of sound intensity is shown in Fig. 2. At the 100% detection sound level, the mean detection rate was 98.26%, and the difference between these two rates was close to significance ( $t[11] = 2.16, p = .054$ ). The mean detection rates at the 75% and 50% detection sound levels were 53.12% ( $t[11] = 2.87, p = .015$ ) and 20.83% ( $t[11] = 3.72, p < .01$ ). The increase in auditory threshold when performing the visual task may have been because the subjects were instructed to focus their attention primarily on the visual task, and secondarily on reporting whether they had heard the sound. The mean percentages for bouncing reports from trials where subjects declared not having heard the sound are shown in Fig. 3. Since the detection threshold at the 100% detection level was 98.26%, there were not enough data to assess a reliable percentage of “bouncing” and “streaming” responses. Consequently, this condition does not appear on the graph. When the sound was not heard, the mean percent of bouncing reports was higher when a sound was present than when not present ( $p < .01$  for the 75% and 50% levels, Newman–Keuls post hoc test). The mean percentage of bouncing reports differed between the 75% and 50% levels ( $p = .044$ , Newman–Keuls post hoc test). These findings indicate that the results from Experiment 1 were not merely due to sounds being consciously heard. However, since in 20% of the trials in Experiment 2, subjects reported that sounds were still heard at the 50% detection level, it cannot be excluded that sounds were heard in a small proportion of Experiment 1 trials. However, we can hypothesize that this proportion is less than 20% since this ratio would include false detections as attested by the non-negligible amount of false detections under “No sound” conditions (mean = 13.89%).

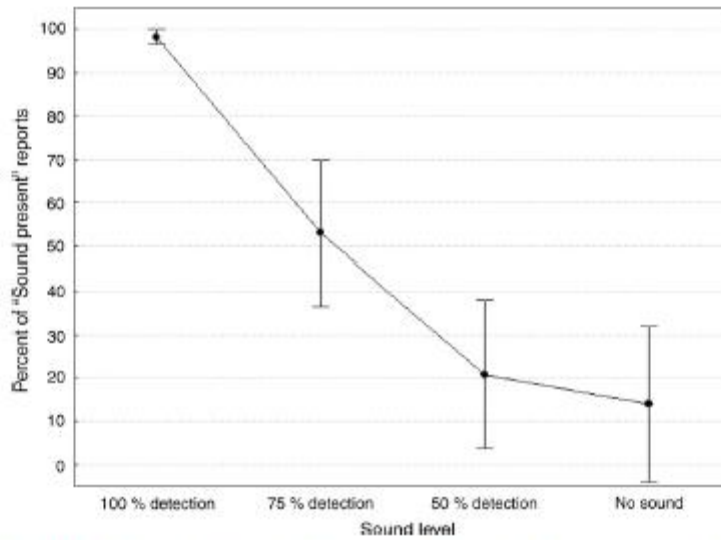


Fig. 2. Mean percentage ( $\pm$ SEM) of "Sound present" reports as a function of sound level. Sound levels are expressed in terms of detection threshold assessed in a previous auditory detection task.

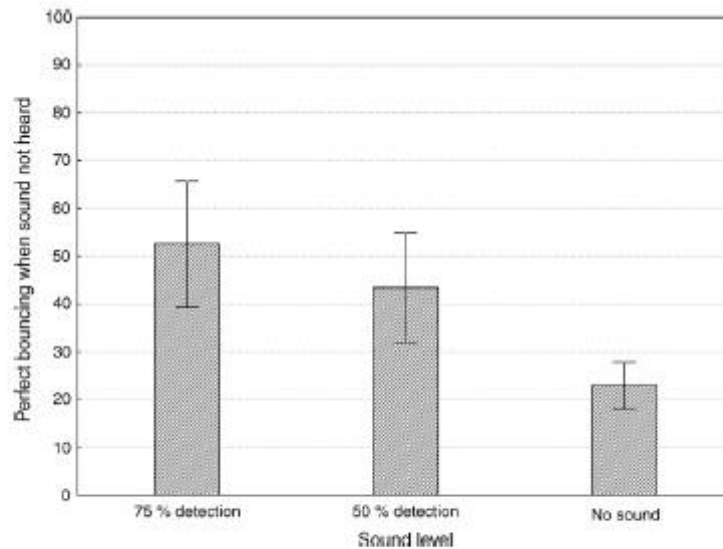


Fig. 3. Mean percentage ( $\pm$ SEM) of reports of stimulus bouncing for trials in which subjects reported not having heard the target sound. Sound levels are expressed in terms of detection threshold assessed in a previous auditory detection task.

#### 4. Experiment 3

Experiments 1 and 2 were designed to ensure that subjects could not be aware of the presence of a sound. While the results of Experiment 2 appeared to confirm this lack of awareness, it might be argued that these sounds were not truly subliminal in all trials even when subjects affirmed not having heard them. Such an objection might find its origin in the still-existing controversy over how to define conscious and unconscious perception and how to rule out alternative weak conscious perception interpretations of putatively unconscious

effects. Briefly, the subjective threshold model proposed by Merikle, Reingold and associates (e.g., Cheesman & Merikle, 1984; Cheesman & Merikle, 1986; Reingold & Merikle, 1988) holds that unconscious perceptual effects occur only under stimulus conditions where participants deny awareness but can still perform above chance on perceptual discrimination tasks. This model denies that unconscious perceptual effects occur under more stringent objective threshold conditions, where forced-choice responding indicates that the stimulus is undetectable. In opposition, the objective threshold/rapid decay model proposed by Greenwald and associates (e.g., Draine & Greenwald, 1998; Greenwald & Draine, 1998) holds that objective thresholds are real but intrinsically very short-lived, and that subjective threshold effects are likely to be weakly conscious perceptual effects (see Snodgrass, Bernat, & Shevrin, 2004, for a review).

Although the present study objective was more aligned with the requirements of the former model, namely to rule out the possibility that subjects “consciously” inferred the bouncing phenomenon from the presence of a sound of which they were aware, a third experiment was designed which met the requirements of the latter model. Hence, the intensity criterion was not set at the subjective threshold but at an objective threshold level, that is, at a level where the sensitivity criterion  $d_0$  equals 0.

Thirteen subjects (6 females, 7 males) who had not participated in Experiments 1 or 2 were enrolled in Experiment 3. Prior to the experiment, subjects were assessed for auditory detection thresholds for a brief sound using the method of constant stimuli. A  $d_0$  equal to 0 implies equal 50% proportions of Hits and False Alarms. The sound level which best met this requirement was set as the stimulus in Experiment 3 for each subject. Hence,  $d_0$  values ranged from  $-0.1$  to  $0.08$ . Experiment 3 was a replication of Experiment 2 except that the 500 Hz sound was presented at only 2 intensities—the intensity which yielded 75% detection and the intensity which yielded a  $d_0$  equal or near to 0. In a third condition the target sound was absent. The intensity yielding 100% detection was not included in the present experiment because the presence of this clearly audible stimulus might have encouraged a conservative response bias in Experiment 2. Thus, when a number of trials have a clearly audible stimulus, and two levels of weaker auditory stimuli, participants might be hesitant to say “Yes” given the context of some stimuli that are clearly suprathreshold. Each of the three conditions was randomly selected and presented 24 times to result in a total of 72 trials.



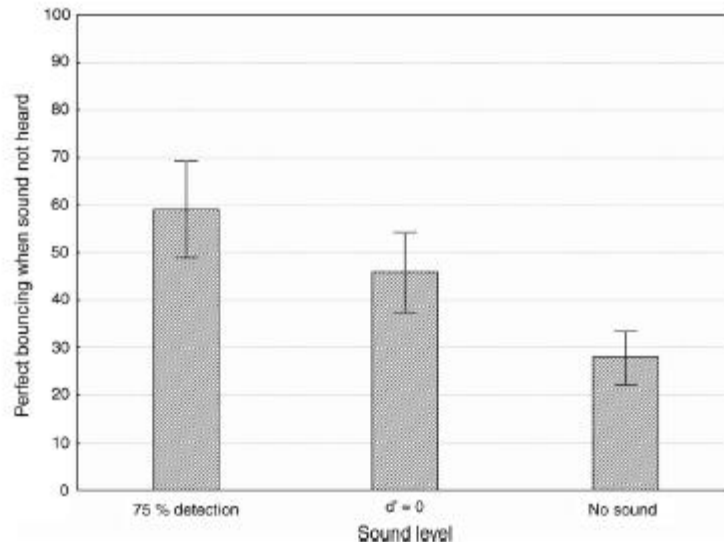


Fig. 4. Mean percentage ( $\pm$ SEM) of reports of stimulus bouncing for trials in which subjects reported not having heard the target sound. Sound levels are expressed in terms of detection threshold (75%) and null sensitivity ( $d' = 0$ ) assessed in a previous auditory detection task.

#### 4.1. Results

The mean percentages for bouncing reports from trials where subjects declared not having heard the sound are shown in Fig. 4. When the sound was not heard, the mean percent of bouncing reports was higher when a sound was present than when not present ( $p < .01$  for the 75% and  $d_0 = 0$  levels, Newman–Keuls post hoc test). The mean percentage of bouncing reports differed between the 75% and  $d_0 = 0$  levels ( $p = .016$ , Newman–Keuls post hoc test). The results of the present experiment are similar to those observed in Experiment 2, which suggests that the  $d_0 = 0$  threshold (i.e., equal 50% probability between Hits and False Alarms) was already reached at the 50% threshold in the previous experiment.

#### 5. Discussions

The present study shows for the first time that visual perception can be modified by the activation of the auditory system without a conscious perception of the auditory stimulus. The effect of the subliminal auditory stimulus on the bouncing–streaming illusion perception observed in this study was comparable to that described in previous studies using supraliminal sounds (Bushara et al., 2003; Sanabria et al., 2004; Sekuler et al., 1997). However, unlike a previous study (Sekuler et al., 1997), the present findings did not show an enhancement of bouncing perception when the sound was presented 150 ms before the moment of coincidence, only when the sound was delivered at or 150 ms afterwards. The results of Experiments 2 and 3 confirmed that the visual effect was due to activation of the auditory system without subjects being conscious of the stimulation since the bouncing perception was higher even in trials in which the subjects declared hearing no sound. The current study found that delayed activation of the auditory system (150 ms post coincidence) affected visual motion perception whereas pre-activation did not. Previous studies found that auditory stimuli presented close to the ear take approximately 13 ms to

activate superior colliculus neurons, while a visual stimulus often requires 65–100 ms to reach the same neurons (Stein & Meredith, 1993). Thus, an explanation for the present findings is that under delayed sound conditions, the visual and auditory stimuli reached integrative multimodal areas in a closer temporal proximity than when sounds were presented prior to the visual stimuli.

Although previous studies (Sekuler et al., 1997) observed an enhancement of the bouncing perception percent even when sound was presented 150 ms prior to coincidence, this may have been due to a cognitive bias, which would imply that the temporal window of intermodal integration is broader under conscious than unconscious processing.

The hypothesis that visual-auditory integration takes place in multimodal areas is supported by a recent neuroimaging study (Bushara et al., 2003) using a variant of the present ambiguous two-dimensional motion display. In that study, brain activation patterns in participants reporting a 'bouncing' percept were compared with those of participants reporting a 'streaming' percept. The study found an enhanced neural response on 'bouncing' (as compared with 'streaming') trials in multimodal brain areas (such as the superior colliculus), together with reduced activity in primarily unimodal areas, consistent with there being a genuine perceptual component to the auditory modulation of ambiguous visual motion perception. The involvement of the superior colliculus in the cross-modal binding process could explain the broad temporal window within which the sound bounce-inducing effect appears to take place. It has been shown that multisensory neurons in this subcortical structure operate optimally within an interactive temporal window of several hundreds of milliseconds (Meredith, Nemitz, & Stein, 1987).

The findings of the present study add to a growing body of research demonstrating that environmental events occurring in one sensory modality can influence the perception of stimuli presented at around the same time in a different sensory modality. However, the present results provide the first behavioral demonstration of the auditory modulation of visual perception in the ambiguous visual motion paradigm that cannot be accounted for by an explicit inference of the audiovisual phenomenon. Paradigms which are not prone to conscious interpretation, such as the one used here, can help underpin perceptual processes and rule out response biases in many cross-modal binding phenomena which have been previously described and extensively studied. It cannot be concluded from the present results that only sensorial levels of processing were activated by the subliminal sounds since it has been shown that semantic levels of processing can be reached by subliminal stimuli and can significantly influence conscious decision making (Cheesman & Merikle, 1984; Dehaene et al., 1998; Merikle & Joordens, 1997). Hence, it would be interesting to determine whether subliminal sounds less suggestive of a collision phenomenon produce similar effects.

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