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 multisensoryinformation is erroneously perceived to be bound together suggest that cross-modal binding is a fast andpre-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 influenceof response bias and other decision factors (Bertelson& de Gelder, 2004).The ‘‘bouncing–streaming’’ illusion involves two objects moving towards one another, reaching the sameposition, 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 bya 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 thetransient auditory stimulus produced by a physical collision of two objects, causing subjects to infer the reversalof motion direction from the presence of this factor generally associated with bouncing in the physicalworld.

Cognitive biases linked to subjective reports in the sound bounce-inducing effect have recently been ruledout by an elegant paradigm (Sanabria et al., 2004) in which the point of coincidence of two moving disks washidden behind an occluder.When emerging from behind the occluder, the disks (one red, the other blue) couldeither follow the same trajectory (streaming) or else move in the opposite direction (bouncing). Participantsmade speeded discrimination responses regarding the side from which one of the disks emerged from behindthe occluder. Participants responded more rapidly on streaming trials when no sound was presented comparedto ‘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 paradigmprovides an implicit/objective behavioral measure of the sound bounce-inducing effect, it does not rule outinterpretative response biases whereby subjects explicitly infer the reversal of motion direction from the presenceof 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 bounceinducedeffect. The approach involved stimulating the auditory system without the subject being conscious ofthe stimulation. This was achieved by presenting a subliminal sound either 150 ms before, at, or 150 ms afterthe moment of coincidence of two disks. An increase in the proportion of ‘‘bounce’’ responses in the presenceof 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 thepurpose of the experiment. Importantly, the subjects were not aware of the presence of a subliminal soundduring the visual motion experiment. The experiment took approximately 20 min to complete and was performedin accordance with the ethical standards stated in the 1964 Declaration of Helsinki. Informed consentwas obtained after the nature and possible consequences of the studies were explained. Audiograms (1702Audiometer Grason-Stadler_) in the 250–8000 Hz range were performed, and all subjects exhibited normalhearing.

2.1.2. Materials

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

2.1.3. Procedure

2.1.3.1. Auditory threshold. Prior to the ‘‘visual motion’’ experiment, an auditory detection threshold for abrief 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 presented400, 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 themethod 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 wasused 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_2) appeared on opposite sides of a dark computer screen. The disks were presentedsymmetrically from one of three possible elevations on the computer screen (at an eccentricity of 8.8_): thedisks appeared at the top of the screen when moving diagonally from top-to-bottom; at the middle when movingon a horizontal trajectory; and at the bottom when moving diagonally from bottom-to-top. In the verticaltrajectory condition the disks appeared, respectively, at the top and bottom of the screen (at an eccentricity of8.8_). The disks moved at 8.8 deg s_1, and a white noise (20–20,000 Hz) of 2 s in duration and 65 dB SPL wassimultaneously delivered through the head phones. A subliminal auditory stimulus was presented 150 msbefore, 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 inrandom order. The trial ended when each disk had reached the other’s starting position, both disks disappearedfrom view and the white noise stopped (i.e., 2 s). Subjects indicated whether the disks appeared tostream through or bounce off one another by pressing one of two possible buttons. No response time constraintwas imposed upon the subjects. After the experiment, subjects were asked whether they had heard asound similar to the one used during the threshold experiment. That debriefing revealed that no subjecthad 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

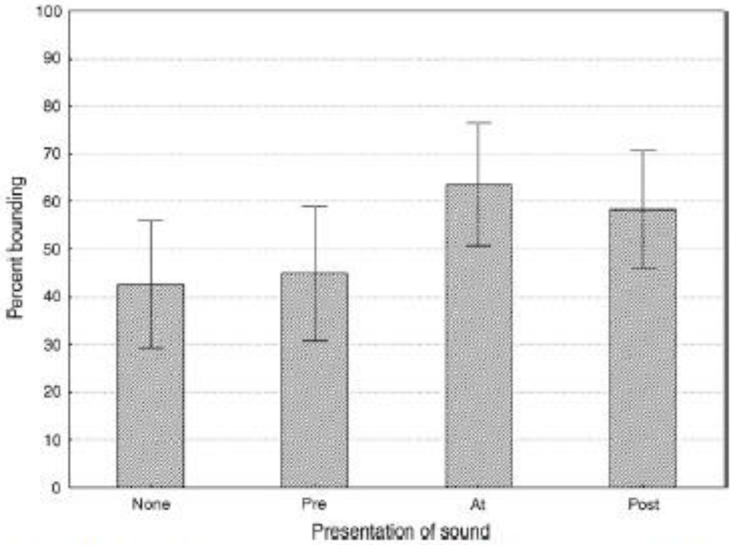

Fig. 1. Mean percentage (±SEM) of reports of stimulus bouncing. Motion was accompanied by a brief sound 150 ms before (Pre) or after (Post) the disk coincidence, or at the moment of coincidence. A control condition presented no sound (none).

or 150 ms later, the bouncing perception proportion was 63.54% and 58.33%, respectively, compared to42.71% for the 'no sound' condition ($p < .05$, Newman–Keuls a posteriori test). The percentages at, themoment of coincidence or 150 msafter, did not significantly differ from each other. The bouncing responsepercent did not significantly differ from the no sound condition when the sound was presented 150 ms beforecoincidence.Although subjects declared they had not heard the 500 Hz target sound embedded in the white noise duringthe visual task, it might be argued that at a 50% detection threshold, the sound might have been heard in sometrails, and that this may explain the observations. Therefore, a second experiment was performed in whichsubjects reported after each trial whether or not they had heard the 500 Hz target sound. We hypothesizedthat if the percentage of bouncing responses remains enhanced in trials where subjects have explicitly declarednot having heard the sound, the observed visual perception effect would most likely be due to activation of theauditory 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 Experiment2.

3.2. Procedure

The same materials were used as in Experiment 1, except that sounds were played through 2 loud-speakersplaced 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 asdescribed in Experiment 1. The visual motion experiment used three 500 Hz sound intensities: (a) the intensitywhich yielded 100% detection, (b) the intensity which yielded 75% detection, and (c) the intensity whichyielded 50% detection. In a fourth condition the target sound was absent. Each of the four conditions wasrandomly selected and presented 24 times to result in a total of 96 trials. Once subjects had responded tothe ‘‘Bounce or Stream’’ question by pressing one of two buttons, they reported on whether they had heardthe 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 wasclose to significance ($t[11] = 2.16$, $p = .054$). The mean detection rates at the 75% and 50% detection sound levelswere 53.12% ($t[11] = 2.87$, $p = .015$) and 20.83% ($t[11] = 3.72$, $p < .01$). The increase in auditory thresholdwhen performing the visual task may have been because the subjects were instructed to focus their attentionprimarily 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 soundare shown in Fig. 3. Since the detection threshold at the 100% detection level was 98.26%, there were notenough data to assess a reliable percentage of ‘‘bouncing’’ and ‘‘streaming’’ responses. Consequently, this conditiondoes not appear on the graph. When the sound was not heard, the mean percent of bouncing reportswas 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 werenot merely due to sounds being consciously heard. However, since in 20% of the trials in Experiment 2, subjectsreported that sounds were still heard at the 50% detection level, it cannot be excluded that sounds wereheard in a small proportion of Experiment 1 trials. However, we can hypothesize that this proportion is lessthan 20% since this ratio would include false detections as attested by the non-negligible amount of false detectionsunder ‘‘No sound’’ conditions (mean = 13.89%).

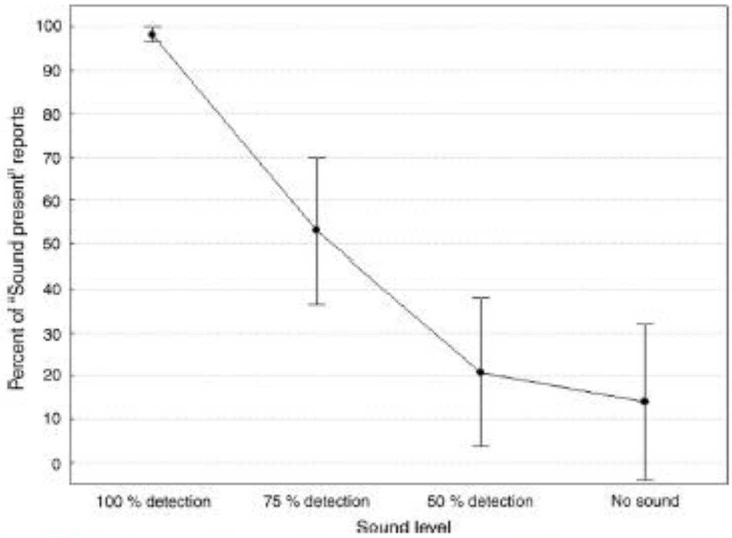

Fig. 2. Mean percentage (±SEM) of "Sound present" reports as a function of sound level. Sound levels are expressed in terms of detection threshold assessed in a previous auditory detection task.

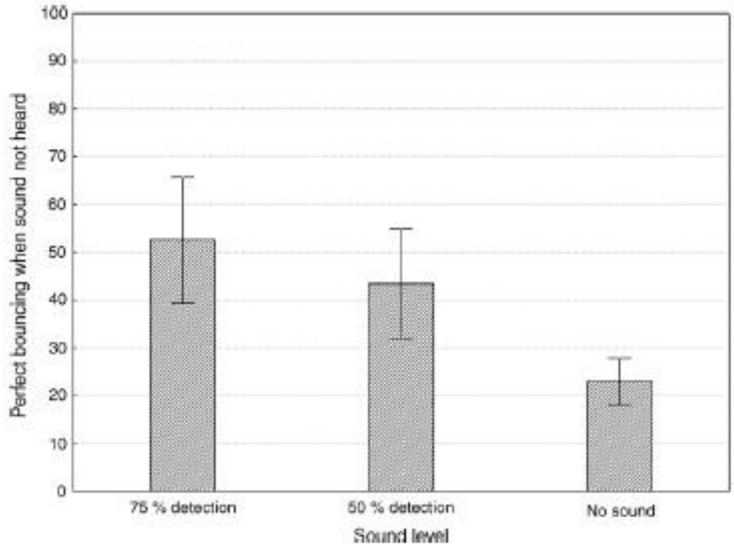

Fig. 3. Mean percentage (±SEM) of reports of stimulus bouncing for trials in which subjects reported not having heard the target sound. Sound levels are expressed in terms of detection threshold assessed in a previous auditory detection task.

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 thesounds were not truly subliminal in all trials even when subjects affirmed not having heard them. Such anobjection 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 unconsciousperceptual effects occur only under stimulus conditions where participants deny awareness but can still performabove chance on perceptual discrimination tasks. This model denies that unconscious perceptual effectsoccur under more stringent objective threshold conditions, where forced-choice responding indicates that thestimulus is undetectable. In opposition, the objective threshold/rapid decay model proposed by Greenwald andassociates (e.g., Draine& Greenwald, 1998; Greenwald &Draine, 1998) holds that objective thresholds arereal but intrinsically very short-lived, and that subjective threshold effects are likely to be weakly consciousperceptual effects (see Snodgrass, Bernat, &Shevrin, 2004, for a review).

Although the present study objective was more aligned with the requirements of the former model, namelyto rule out the possibility that subjects ''consciously'' inferred the bouncing phenomenon from the presence ofa sound of which they were aware, a third experiment was designed which met the requirements of the lattermodel. 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 d0 equals 0.

Thirteen subjects (6 females, 7 males) who had not participated in Experiments 1 or 2 were enrolled inExperiment 3. Prior to the experiment, subjects were assessed for auditory detection thresholds for a briefsound using the method of constant stimuli. A d0 equal to 0 implies equal 50% proportions of Hits and FalseAlarms. The sound level which best met this requirement was set as the stimulus in Experiment 3 for eachsubject. Hence, d0 values ranged from _0.1 to 0.08. Experiment 3 was a replication of Experiment 2 exceptthat the 500 Hz sound was presented at only 2 intensities—the intensity which yielded 75% detection andthe intensity which yielded a d0 equal or near to 0. In a third condition the target sound was absent. The intensityyielding 100% detection was not included in the present experiment because the presence of this clearlyaudible stimulus might have encouraged a conservative response bias in Experiment 2. Thus, when a numberof trials have a clearly audible stimulus, and two levels of weaker auditory stimuli, participants might be hesitantto say ''Yes'' given the context of some stimuli that are clearly suprathreshold. Each of the three conditionswas randomly selected and presented 24 times to result in a total of 72 trials.

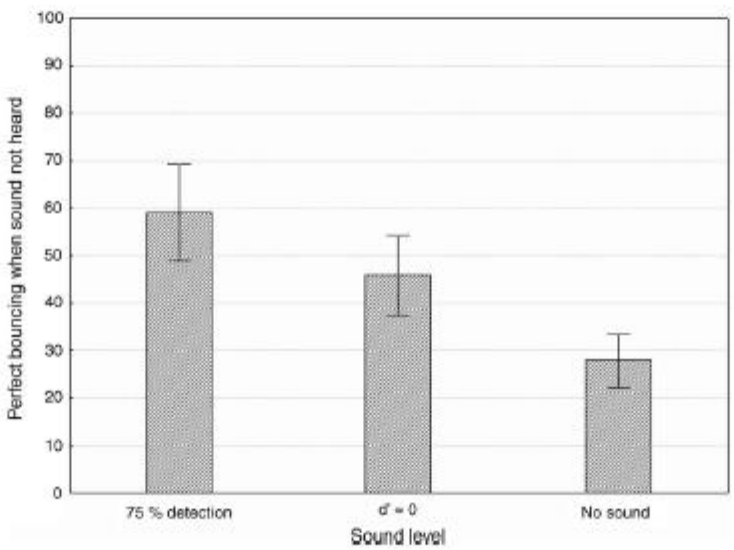

Fig. 4. Mean percentage (±SEM) of reports of stimulus bouncing for trials in which subjects reported not having heard the target sound. Sound levels are expressed in terms of detection threshold (75%) and null sensitivity ($d' = 0$) assessed in a previous auditory detection task.

4.1. Results

The mean percentages for bouncing reports from trials where subjects declared not having heard the soundare shown in Fig. 4. When the sound was not heard, the mean percent of bouncing reports was higher when asound was present than when not present ($p < .01$ for the 75% and d0 = 0 levels, Newman–Keuls post hoc test).The mean percentage of bouncing reports differed between the 75% and d0 = 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 d0 = 0 threshold (i.e., equal 50% probability between Hits and False Alarms) wasalready 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 theauditory system without a conscious perception of the auditory stimulus. The effect of the subliminal auditorystimulus on the bouncing–streaming illusion perception observed in this study was comparable to thatdescribed in previous studies using supraliminal sounds (Bushara et al., 2003; Sanabria et al., 2004; Sekuleret al., 1997). However, unlike a previous study (Sekuler et al., 1997), the present findings did not show anenhancement 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 thatthe visual effect was due to activation of the auditory system without subjects being conscious of the stimulationsince 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) affectedvisual motion perception whereas pre-activation did not. Previous studies found that auditory stimuli presentedclose to the ear take approximately 13 ms to activate superior colliculus neurons, while a visual stimulusoften requires 65–100 ms to reach the same neurons (Stein & Meredith, 1993). Thus, an explanation for thepresent findings is that under delayed sound conditions, the visual and auditor stimuli reached integrative multimodalareas 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 percenteven when sound was presented 150 ms prior to coincidence, this may have been due to a cognitive bias, whichwould imply that the temporal window of intermodal integration is broader under conscious than unconsciousprocessing.

The hypothesis that visual-auditory integration takes place in multimodal areas is supported by a recentneuroimaging study (Bushara et al., 2003) using a variant of the present ambiguous two-dimensional motiondisplay. In that study, brain activation patterns in participants reporting a 'bouncing' percept were comparedwith 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 perceptualcomponent to the auditory modulation of ambiguous visual motion perception. The involvement of the superiorcolliculus in the cross-modal binding process could explain the broad temporal window within which thesound bounce-inducing effect appears to take place. It has been shown that multisensory neurons in this subcorticalstructure 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 environmentalevents occurring in one sensory modality can influence the perception of stimuli presented at around the sametime in a different sensory modality. However, the present results provide the first behavioral demonstration ofthe auditory modulation of visual perception in the ambiguous visual motion paradigm that cannot beaccounted for by an explicit inference of the audiovisual phenomenon. Paradigms which are not prone to consciousinterpretation, 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 thesubliminal sounds since it has been shown that semantic levels of processing can be reached by subliminalstimuli and can significantly influence conscious decision making (Cheesman&Merikle, 1984; Dehaeneet 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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