The Beep-Speed Illusion: Non-Spatial Tones Increase Perceived Speed of Visual Objects in a Forced-Choice Paradigm

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Highlights

- We report an auditory-induced illusory increase in perceived visual object speed
- Synchronizing non-spatial tones with direction changes elicits this illusion
- Eye movements cannot account for the illusory increase in speed
- The results suggest a guidance of spatial attention toward the synchronized object

Abstract

We introduce a new audio-visual illusion revealing the interplay between audio-visual integration and selective visual attention. This illusion involves two simultaneously moving objects that change their motion trajectory occasionally, but only the direction changes of one object are accompanied by spatially uninformative tones. We observed a selective increase in perceived object speed of the audio-visually synchronized object by measuring the point of subjective equality in a forced-choice paradigm. The illusory increase in perceived speed of the audio-visually synchronized object persisted when preventing eye movements. Using temporally matched color changes of the synchronized object also increased the perceived speed. Yet, using color changes of a surrounding frame instead of tones had no effect on perceived speed ruling out simple alertness explanations. Thus, in contrast to coinciding tones, visual coincidences only elicit illusory increases in perceived speed when the coincidence provided spatial information. Taken together, our pattern of results suggests that audio-visual synchrony attracts visual attention towards the coinciding visual object, leading to an increase in speed-perception and thus shedding new light on the interplay between attention and multisensory feature integration. We discuss potential limitations such as the choice of paradigm and outline prospective research question to further investigate the effect of audio-visual integration on perceived object speed.

206 words

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In most everyday life situations, human observers face an almost endless stream of sensory information from different modalities that the mind needs to integrate in order to extract a coherent representation of the outside world (Ernst & Bühlhoff, 2004; Rahnev, & Denison, 2018). Within the last two or three decades, audio-visual integration has been subject to intensive research (for reviews see Chen & Spence, 2017a; Koelewijn et al., 2010; Talsma et al., 2010). In particular, several audio-visual illusions have provided strong empirical demonstrations of audio-visual integration and have inspired subsequent theoretical development. For instance, substantial integration-induced changes in the perceived quantity of events (e.g. Shams, Kamitani, & Shimojo, 2000), the perceived salience of stimuli (Vroomen & De Gelder, 2000), and even the established correspondence between moving objects (Sekuler, Sekuler, & Lau, 1997) have been observed.

A strong prerequisite for audio-visual integration is temporal synchrony. Typically, only auditory and visual stimuli that arise within a temporal window of ± 200 -300 milliseconds are merged into a common percept (Dixon & Spitz, 1980; Meyerhoff & Suzuki, 2018; Zampini et al., 2005). Beyond such temporal factors, however, the availability of attentional resources also strongly impacts audio-visual integration. Audio-visual integration falters under high attentional loads (Alsus et al., 2005) or during distraction (McGurk & MacDonald, 1976) and allocating attention to the visual stimulus itself (Lunn et al., 2019) or its spatial area promotes audio-visual integration (Jensen et al., 2019; van der Burg et al., 2012). Importantly, however, the interplay of attention and audio-visual integration appears not to be unidirectional, as audio-visual integration is also capable of guiding visual attention (Talsma et al., 2010). In particular, in cluttered visual search displays, targets that change their color in synchrony with non-spatial tones are detected faster than targets without such audio-

visual synchrony (van der Burg et al., 2008). This observation suggests that – under some temporal constraints (Fujisaki et al., 2006) – attention can be guided by audio-visual synchrony during an active search task. The exact interplay of attention and audio-visual integration, however, is far from being understood because relevant topics such as automaticity, general constraints, or the level of integration (e.g., early vs. late integration) are still discussed controversially (for a review, see Koelewijn et al., 2010).

With the present study, we intend to promote the understanding of this interplay between audio-visual integration and visual attention by exploring a new audio-visual interaction¹. We investigated whether visual attention selects one (out of two) moving objects whose changes in the direction of motion are temporarily aligned with brief, spatially uninformative tones. We measured the effect of selective attention with a known perceptual consequence of the allocation of visual attention: an intensified visual percept (Carrasco et al., 2004), which is an (auditory-induced) illusory increase in perceived object speed in the present set of experiments. In Experiments 1a and 1b, we introduce the ‘beep-speed’ illusion and show that coinciding non-spatial tones elicit the basic illusion with and without possible eye movements. In Experiment 2, we directly compared the effectiveness of the non-spatial tone in eliciting the illusory increase in perceived object speed with a spatial visual cue (a color change of the coinciding object) as well as a non-spatial visual cue (a color change of a surrounding outline). Both the coinciding non-spatial tones and the spatial visual cues induced the illusory increase in perceived object speed. In contrast to the coinciding tones, however, the non-spatial visual cue did not increase the perceived object speed.

¹ We accidentally “discovered” this illusion while working on dynamic displays including multiple moving objects. When the direction changes of one of the objects were coincident with a brief tone, this object appeared to move faster than the others.

Experiment 1a

In this experiment, we introduced the beep-speed illusion: an illusory sound-induced object acceleration. Demonstration videos of this experiment are available at https://www.iwm-tuebingen.de/public/realistic_depictions_lab/beep_speed_illusion.

Methods

Participants

The final sample consisted of 25 students (20 female, 20-27 years). Five additional participants were excluded (see results for details). We chose to test a total sample of 30 participants (and repeated it in all subsequent experiments) due to the following considerations: The most relevant statistical test in our manuscript is the comparison of the observed point of subjective equality with the point of objective equality (i.e. whether there is an illusory increase in perceived object speed). Introspectively, the illusion can be experienced within a single trial. Therefore, we expected a large effect size for the comparison of the point of subjective equality against the constant of 4.5° of visual angle ($d_z > 0.8$). With power $(1 - \beta) > .8$ at $\alpha = .05$, this would result in a sample size of 23 participants (g*power; Faul et al., 2007). We decided to slightly overpower this sample size in order to compensate for potential data exclusions as well as potential weaker manifestations of the illusion as there are no previous studies from which we can derive effect sizes. All experiments were ethically approved by the institutional review board of the Leibniz-Institut für Wissensmedien, Tübingen, and all participants provided informed consent prior to testing.

Apparatus

All stimuli were coded using the PsychoPy libraries (Pierce, 2007). Experiment 1a was presented on a 23-inch LCD screen (60 Hz, 1920 x 1200 pixels) controlled by a MacMini at

an unrestricted viewing distance of approximately 60 cm. All auditory stimuli were administered by standard Logitech headphones.

Stimuli and Procedure

Stimuli were two white discs (0.7 deg in diameter) that moved against a black background. Each disc moved inside an invisible square of 25 x 13 deg. The two invisible squares were positioned left and right from the center of the screen (separated by 0.5 deg). The motion interval lasted 3000 ms. Within each interval of 1000 ms, both objects changed their direction of motion once with the restrictions that there was a minimum interval of 250 ms between any direction changes as well as between direction changes at the beginning or at the end of a trial. The angular difference between old and new directions varied randomly between 60 deg and 120 deg with the restriction that none of the objects touched the boarder of the invisible square. To ensure the temporal and spatial restrictions, the motion paths were generated offline (we generated a separate set of trials for each participants). The speed of one of the objects was 4.5 deg/s, whereas the speed of the other object varied from 2.75 deg/s to 6.25 deg/s in steps of 0.5 deg/s. In all trials, a brief tone (500 Hz, 67 ms, ~60 dB) coincided with the direction changes of the objects moving at 4.5 deg/s. We refer to this object as the audio-visual object. Importantly, the tone did not carry any spatial information. The side (i.e. left vs. right) of the object coinciding with the tones was counterbalanced across trials² (see Figure 1).

² We have counterbalanced the side of the audio-visual object as hemifield effects have been observed in previous research on audio-visual integration (Chen & Spence, 2017b). An exploratory analysis of the hemifield effects is available in the electronic supplementary materials (ESM). Briefly summarized, there were no effects of the hemifield in Experiment 1a, but objects in the right hemifield appeared to generally move faster than objects in the left hemifield in Experiments 1b and 2. In particular, the analysis of Experiment 2 revealed that hemifield effects were independent of the beep-speed illusion. The coinciding tones increased perceived speed equally in both hemifields (i.e., no interaction between coinciding transients and hemifield of the synchronized object).

Figure 1. Illustration of the stimulus display (the dashed squares indicate areas of object motion and are invisible to observers). Two objects moved while changing their direction of motion (fading indicates motion history). The direction changes of the object on the left side coincided with brief tones (side counterbalanced). This object always moved at 4.5 deg/s. Between the trials, the speed of the other, purely visual object varied from 2.75 deg/s to 6.25 deg/s.

Following the motion interval, the participants indicated which object they perceived to be moving faster by pressing the X- or the M-key on the keyboard. Each participant completed 8 blocks consisting of 32 (16 trials for each combination of side and speed of the visual object) trials preceded by 10 practice trials.

Results

We analyzed the binary responses (visual object faster vs. audio-visual object faster) using generalized linear models with logit linking functions. We fitted two models for each participant. The first model included an intercept only, whereas the second model included the intercept and a slope for the objective speed of the visual object. To ensure that the participants followed the task instructions, we first compared the intercept model with the model including the slope for the speed of the visual object. For all participants, the model with the speed parameter explained the data significantly better than the intercept model. Thus, all participants systematically varied their responses with the objective differences in

motion speeds (i.e. no participant answered randomly). However, for four participants, the estimated point of subjective equality (PSE; i.e. the speed at which participants balance their “faster” responses equally between both objects) was above 6.25, indicating that these participants had reported the audio-visual object to be faster on a majority of the trials even at the fastest visual object speeds. Due to the large variance, none of these values were outliers (i.e. within the 3 SD range). Nevertheless, we removed these participants as their PSE estimates were likely to be unreliable. One further participant with a PSE of 6.20 deviated more than 3 SD from the new group mean and was also removed. Please note that these are rather conservative exclusions as they remove the five participants with the largest illusory impressions from the data set.

From the intercept and slope parameters, we calculated the PSE for each participant. On average, the PSE was larger than 4.5 deg/s indicating that the visual object needed to move faster than the audio-visual object to match it in perceived speed, $M = 4.71$, $SD = 0.27$. This difference was significant, $t(24) = 3.84$, $p < .001$, $d_z = 0.77$, 95%-CI [.50, 1.12]³, and matches an illusory increase in perceived speed of the audio-visual object of 4.62% (see Figure 2). In addition to the PSEs, we calculated the just noticeable differences (JND; i.e., the difference in speed between the 50% and the 75% threshold; see Table 1). As for most effects of attention in forced-choice paradigms, the JNDs were smaller than the shifts in the PSE (we will return to this in the general discussion).

³ We used a bootstrapping procedure with 10,000 iterations to estimate the confidence intervals of the reported effect sizes.

Figure 2. Results of Experiment 1a (basic illusion with unrestricted eye movement). The black dots represent group mean data; the error bars indicate within-subject confidence intervals. The dashed lines represent individual fits of the psychometric functions. Points of subjective equality (dotted lines) larger than 4.5 deg/s (solid line) signal the presence of the illusory increase in object speed.

Table 1: Shifts in the Point of Subjective Equality (PSE) and Just Noticeable Differences (JND)

	Shift in PSE		JND	
	<i>M (SD)</i>	Range	<i>M (SD)</i>	Range
Experiment 1a				
Tone	0.21 (0.27)	[-0.17, 0.77]	0.86 (0.29)	[0.46, 1.59]
Experiment 1b				
Tone	0.28 (0.35)	[-0.45, 1.14]	1.15 (0.52)	[0.40, 2.75]
Experiment 2				
Tone	0.28 (0.30)	[-0.26, 0.97]	0.95 (0.31)	[0.44, 1.73]
Object Color	0.39 (0.39)	[-0.10, 1.51]	0.99 (0.39)	[0.43, 2.09]
Frame Color	0.03 (0.20)	[-0.70, 0.39]	0.94 (0.35)	[0.31, 1.75]

Note: PSE = Point of Subjective Equality; JND = Just Noticeable Difference

Experiment 1b

The results of Experiment 1a suggest an illusory increase in perceived speed for the one of the two objects for which the direction changes were synchronized with the brief tones. As previous work has indicated that the presentation of tones alters eye-movements (e.g., Zou, Müller, & Shi, 2012) and that eye-movements might interfere with speed perception (e.g., Goettker, Braun, Schütz, & Gegenfurtner, 2018; Turano & Heidenreich, 1999), we ran a control experiment to exclude an effect on eye-movements as an explanation for the beep-speed illusion. To do so, we reran Experiment 1a, but enforced a central fixation throughout the entire experiment.

Methods

All methods were identical to Experiment 1a with the exceptions outlined below.

Participants

The final sample consisted of 27 new students (24 female, 18-30 years). Additional data from three participants was excluded (see results for details).

Apparatus

In this experiment, we recorded eye movements using a SMI red eye-tracker (60 Hz). A chinrest restricted the viewing distance to 60 cm; the stimuli were presented on a 19-in LCD screen (60 Hz, 1280 x 1024 pixels) controlled by a windows notebook.

Stimuli and Procedure

The displays were identical to Experiment 1a with an additional fixation cross (0.6 x 0.6 deg) that was presented in the center of the screen. The participants were instructed to

maintain a central fixation throughout the motion interval. Each trial started after the eye tracker recorded a 167 ms central fixation. When the gaze deviated more than 1 deg from the center of the fixation cross for more than 83 ms, the trial was aborted and an error message emphasizing the central fixation appeared onscreen. These trials were removed from subsequent analyses (12.80%).

Results

As in Experiment 1a, we submitted the binary responses to two generalized linear models with logit linking functions (intercept model vs. model with visual object speed) for each participant. The model comparison revealed that the responses of one participant did not vary with the objective speed of the visual object (i.e. random answers). Data from this participant was excluded from the analyses. After extracting the PSE separately for each participant, we excluded data from two further participants who differed more than 3 SD from the group mean. On average, the PSE for the speed of the visual object was larger than 4.5 deg/s, $M = 4.78$, $SD = 0.35$. This difference was significant, $t(26) = 4.12$, $p < .001$, $d_z = 0.79$, 95%-CI [0.47, 1.24] and matches an illusory increase in speed of 6.24% (see Figure 3). The corresponding JNDs are available in Table 1. This finding rules out the potential alternative explanation that the illusory increase in speed emerges from eye movements.

Figure 3. Results of Experiment 1b (prevented eye-movements). The black dots represent group mean data; the error bars indicate within-subject confidence intervals. The dashed lines represent individual fits of the psychometric functions. Points of subjective equality (dotted lines) larger than 4.5 deg/s (solid line) signal the presence of the illusory increase in object speed.

Experiment 2

In Experiments 1a and 1b, we observed that an object which changed its direction of motion in temporal synchrony with the spatially uninformative tone appeared to move faster than the simultaneously present unsynchronized object. In this experiment, we investigated visuo-spatial attention as a candidate mechanism for this illusion. More specifically, we pursued the hypothesis that the misperception of the object speed arises from shifts in visual attention elicited by the temporal synchrony of the visual direction changes and the (non-spatial) tones. An observation that is essential for this hypothesis stems from research on

unimodal visual attention. When visual attention is guided toward an object, it intensifies the appearance of the selected objects and stimulus dimensions such as contrast (Carrasco et al., 2004), spatial frequency (Gobell & Carrasco, 2005), or motion signals (Cavanagh, 1992; Chaudhuri, 1990). For instance, Turatto et al. (2007) observed that participants perceived the grating of an attended Gabor patch as moving faster than the grating of an unattended Gabor patch. This striking similarity in the phenomenology in these purely visual displays inspired us to further explore the role of attention for our illusory sound-induced object acceleration.

To explore the hypothesis that spatial shifts in attention toward the audio-visually synchronized object elicit the illusory increase in speed, we compared three different transients coinciding with the visual direction change in this experiment. First, we replicated the condition with spatially uninformative tones which induced the illusion in Experiments 1a and 1b. Second, we introduced a purely visual condition in which we replaced the sound with a spatially informative color change of the corresponding visual object (from white to red and back) coinciding with the direction changes. Such a color change has been demonstrated to attract visual attention (e.g., Lu & Zhou, 2005). Thus, if the tone biases spatial attention toward the coinciding object, the color change should induce a similar phenomenology. Third, we introduced a condition in which we replaced the sound with a spatially uninformative color change of an outline surrounding the complete visual scene coinciding with the direction changes. We implemented this condition because we aimed to compare the spatially uninformative tones with a spatially uninformative visual cue. Such a comparison is necessary to rule out effects of alertness as an alternative explanation for the beep-speed illusion. Critically, the color change of the outline has the same temporal coincidence as the color change of the object but does not involve spatial information (as it includes both objects). Thus, this transient should not bias visuo-spatial attention towards one of the objects and therefore leave perceived object speed unaffected.

Methods

All methods, analyses, and hypotheses regarding this experiment have been preregistered at the Open Science Framework (OSF; <https://osf.io/mt9sx>). Demonstration videos of this experiment are available at https://www.iwm-tuebingen.de/public/realistic_depictions_lab/beep_speed_illusion.

Participants

The final sample consisted of 28 students (25 female, 18-32 years). Additional data from two participants was excluded (see results for details).

Apparatus, Stimuli, and Procedure

All apparatus, stimuli, and the procedure were identical to Experiment 1a with the following exceptions. There was a white outline (25 x 13 deg, 10 pixels line width, approx. 0.27 deg) drawn around the area of potential object movement (i.e. both objects move inside the outline). There were three experimental conditions (one audio-visual and two purely visual) in which we manipulated the type of the transient that coincides with the direction changes of the object moving at a constant speed of 4.5 deg/s. In the first condition, the coinciding transient was a tone identical to Experiments 1a and 1b. In the second condition, the object moving at constant speed (i.e. the audio-visual object in Experiments 1a and 1b) changed its color from white to red for 67 ms, coinciding with the direction changes. Finally, in the third condition, the coinciding transient was a 67 ms color change from white to red of the surrounding outline. Each participant completed 8 blocks consisting of 96 (16 trials for each combination of transient, side and speed of the visual object) experimental trials preceded by 10 practice trials. We repeated the motion paths across conditions to rule out any potential influences from the characteristics of the motion paths.

Results

We submitted the binary responses to two generalized linear models with logit linking functions (intercept model vs. model with visual object speed) for each participant and condition. The model comparison revealed that two participants did not vary their responses with the objective speed of the visual object (i.e. random answers). The data from these participants were excluded from further analyses.

We extracted the PSE separately for each participant and each condition. In the condition with tones as coinciding transients, the mean PSE was significantly larger than 4.5 deg/s indicating faster perceived speed for the audiovisual object, $M = 4.78$, $SD = 0.30$, $t(27) = 4.92$, $p < .001$, $d_z = 0.93$, 95%-CI [0.61, 1.41]. This matches an illusory increase in perceived speed of 6.30%. In the condition with the color change of the object, the mean PSE was also significantly larger than 4.5 deg/s, $M = 4.89$, $SD = 0.39$, $t(27) = 5.34$, $p < .001$, $d_z = 1.01$, 95%-CI [0.78, 1.39]. This matches an illusory increase in perceived speed of 8.76%. In the condition with the color change of the surrounding frame, there was no illusory increase in perceived object speed for the object that coincided with the color changes of the surrounding frame, $M = 4.53$, $SD = 0.20$, $t(27) = 0.79$, $p = .439$, $d_z = 0.14$, 95%-CI [-0.19, 0.69].

Direct comparisons of the PSEs (see Figure 4) revealed that they did not significantly differ between the sound and the object color condition, $t(27) = 1.16$, $p = .257$, $d_z = 0.22$, 95%-CI [-0.17, 0.54]. However, both the sound condition, $t(27) = 3.99$, $p < .001$, $d_z = 0.75$, 95%-CI [0.41, 1.25], and the object color condition, $t(27) = 5.80$, $p < .001$, $d_z = 1.10$, 95%-CI [0.79, 1.55], differed significantly from the condition with the color change of the frame. Thus, the tone and the color change of the object induced the illusory increase in speed at a comparable level, whereas the color change of the surrounding frame did not alter perceived speed. The JNDs for each condition are available in Table 1.

Figure 4. Results of Experiment 2: coinciding tones (left panel) vs. color changes of the object (middle panel) vs. and color changes of the surrounding outline (right panel). The black dots represent group mean data; the error bars indicate within-subject confidence intervals. The dashed lines represent individual fits of the psychometric functions. Points of subjective equality (dotted lines) larger than 4.5 deg/s (solid line) signal the presence of the illusory increase in object speed.

General Discussion

We observed that spatially uninformative tones which were aligned with the direction changes of one of two simultaneously moving objects elicited a shift in the PSE for judged object speed within a forced-choice paradigm. This shift in the PSE is compatible with an illusory increase in perceived speed of approximately 5% (we discuss alternative views later). The visual phenomenology of this effect remarkably matches with the effects of shifts in unimodal visual attention which have been shown to intensify perceptual impressions of the attended object (Carrasco et al., 2004) including motion signals (Turatto et al., 2007). Thus, a shift in selective attention elicited by the temporal synchrony between the spatially uninformative tone and the visual direction change of the moving object is a candidate process explaining the beep-speed illusion. In particular, our comparison of the spatially uninformative tones with the (spatially informative) purely visual color changes of the synchronized objects (Experiment 2) is consistent with this interpretation. Both coinciding tones as well as color changes of the object revealed a comparable illusory increase in perceived speed, suggesting that the tones not only guide attention toward the synchronized object, but also do so rather efficiently at the level of an abrupt color change. Further support

for such a potential guidance of attention emerges from a study by Staufenbiel, van der Lubbe, and Talsma (2011) that showed an increase in sensitivity for visual direction changes among multiple moving objects when a spatially uninformative tone coincides with the direction changes. Importantly, however, our results cannot be explained with pure alerting effects such as a general boost of attention following the tone because neither does the color change of the outline induce the illusion despite providing the same temporal information, nor can simple alertness effects explain the spatial selectiveness of the beep-speed illusion.

An intriguing possibility why non-spatial tones guide spatial visual attention emerges from the distinct retinotopic versus head-centered coordinate systems between both modalities during early stimulus processing (see Störmer, 2019, for a review). Apparently, both coordinate systems can be matched as there is evidence that spatial sounds attract visual attention toward the corresponding visual location, resulting in improved detectability (McDonald et al. 2000), discriminability (Spence & Driver, 1997), as well as an intensified visual appearance of objects at this location (Störmer et al., 2009). However, such effects seem to emerge only when the tone precedes the visual presentation. With the simultaneous presentation in our experiments, however, the temporal synchrony might serve as a heuristic indicating that the location of sound matches the location of the visual event, comparable to the ventriloquism illusion (Bertelson & Aschersleben, 1998). Converging evidence for this argument emerges from a study of van der Burg et al. (2013) showing that tones are bound to only one visual object when multiple objects compete for attentional allocation.

Apparently, more research is necessary to further corroborate the link between attentional guidance by the audio-visually synchronous direction change and the visual appearance of the object speed. One intriguing possibility to further explore this link are individual differences. As for many other audio-visual illusions (e.g., Stevenson, Zemtsov, & Wallace, 2012), there was substantial variation among our participants in the strength of the beep-speed illusion. While the response pattern of the vast majority of our participants

suggests the presence of the beep-speed illusion, there were also a few participants for whom the illusion appeared to be absent (anecdotally, we observed this in our set of reviewers as well). Therefore, if attentional guidance drives the beep-speed illusion, individual differences in the magnitude of the beep-speed illusion as well as attentional guidance should be correlated.

One limitation for interpreting our results arises from the forced-choice paradigm that we used. In this paradigm, the participants have to pick one of the objects without having the possibility to report that both objects do look identical in speed. Although a condition with equal object speeds does not exist in our experiments, such a visual impression might also apply to conditions with rather small objective differences in object speed. This allows for two alternative explanations that need to be considered. Both alternatives have been vividly discussed in the research on the effect of attention on perceived contrast (Carrasco et al., 2004; see Carrasco & Barbot, 2019, for a recent review).

First, it might be possible that difference decision criterions might drive the shift in the PSE toward the attentionally cued objects (e.g., Schneider & Komlos, 2008; Schneider & Malik, 2021). In our displays, this would be the case if attention is guided toward the audio-visually synchronous object, which is then selected due to its salience rather than an increase in speed. It is noteworthy, however, that biases in the simplest form (e.g., select the object on the cued side) were unable to explain the result pattern for perceived contrast (see Carrasco & Barbot, 2019) or perceived speed (e.g., Turatto et al., 2007), as a reversal of the task instructions (e.g., to respond to the slower object) confirmed the results. Of course, these previous results do not necessarily transfer to our set of experiments but given the strong subjective phenomenology, we are confident that simple decision biases do not explain our results (we initially noticed the illusion when working on another task as one of multiple objects appeared to move faster).

Second, a shift in the PSE in a forced-choice paradigm does not necessarily imply that the illusory increase in speed is sufficient to pass the threshold of subjective awareness (see Turatto et al., 2007, for an intensive discussion). Despite the lack of awareness, such an illusion could be capable of affecting visual performance. Previous research has argued that such a situation might apply when the JND is larger than the shift in the PSE; however, since the JND is defined statistically rather than psychologically, this threshold does not necessarily reflect the level of awareness (please note also that our experiments were not intended to measure the JND precisely). In order to provide evidence beyond the anecdotal evidence of the first observation of the beep-speed illusion by us, prospective research should explicitly address the question whether the beep-speed illusion arises at the level of awareness by combining force-choice and detection paradigms (see Anton-Erxleben, Abrams, & Carrasco, 2011; Zhou, Buetti, Lu, & Cai, 2018).

At first sight, the beep-speed illusion seems difficult to integrate with previous findings demonstrating that coinciding tones induce freezing effects in briefly visible displays (Vroomen & de Gelder, 2000). We think, however, that both phenomena might arise from distinct ways of allocating visual attention. Whereas the (spatial) allocation of attention towards a visual object increases perceived speed (see Turatto et al., 2007), the temporal peak in the allocation of attention might prolong the experienced duration of the target display thus causing freezing effects (see Tse et al., 2004). As the present set of experiments is the first report of the beep-speed illusion, further research is necessary to explore the determinants as well as the boundary conditions of this audio-visual illusion. In any case, however, the striking phenomenology as well as quantifiability of the illusory increase in perceived object speed render this illusion a promising road for a better understanding the interplay between audio-visual integration and attentional selection.

Open Practices Statement

Experimental scripts, raw data, and scripts for the analyses of the data are available at <https://osf.io/ym6sp/>. Experiments 1a and 1b were not formally preregistered. The formal preregistration of Experiment 2 is available at <https://osf.io/mt9sx>.

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