Time Perception:
Audio Perception with Visual Cues

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Time perception poses a fascinating but, as yet, unsolved puzzle in neuroscience. Because the process by which we estimate time durations often involves summing information from more than one of the five senses, it is possible to induce illusions where one modality 'tricks' another modality [1]. Investigating these illusions may facilitate understanding of the overall mechanisms of time perception itself. With a deeper understanding of time perception, we may discover improvements in fields as far-flung as sports training, website design, or even the improvement of diagnosis and treatments in mental health. In this preliminary study, we propose that varying the frequency at which a strobe light is projected – at 200 Hz and 400 Hz, as well as 17,000 Hz (perceived as constant light) and no light – will cause participants to misestimate how long an auditory stimulus in the same environment lasted. Specifically, we propose that high frequency strobe lights will cause slowed auditory time perception and thus overestimates of how long an auditory stimulus actually lasted, as opposed to lower frequency strobe lights will cause faster time estimates. Although our initial results were statistically inconclusive, the general trends in the data set imply that our hypothesis may still be valid; further investigations are merited.

At the MIT Edgerton center, a fast strobe light illuminates falling water in such a way that it is possible to observe individual droplets. Depending on how fast the strobe projects, it may appear that the water droplets are falling at different rates, that they are falling more slowly than usual, or even that they are standing still: http://web.mit.edu/Edgerton/www/WaterPiddler.html The Edgerton center website describes the phenomenon in the following way:

> "When you look at the stream underneath the strobe light, which in reality is a series of continuous water droplets flowing downwards at a constant rate, [unlike usual conditions] your eye can see individual droplets making up the stream…When the droplets appear stationary, [it is because] the frequency of the strobe light matches the speed of the water droplets – every flash exposes a different water droplet [but they appear to be] in the same position."

Part of what is so fascinating about this is that a normally continuous event (the rate at which water falls) appears to be occurring abnormally slowly when we view it under changing light conditions. This draws attention to the power of strobes to affect our time perception. Could the use of strobe lights affect more than just the perception of how fast water molecules are moving? Furthermore, would audition be fooled in the same way as the visual system was—if the auditory system were subjected to a visual strobe projected at just the right speed, would it too report that time had slowed down? There does appear to be evidence of the reverse occurring: auditory cues affecting visual time perception. In 2000, Shams and Shimojo found that hearing short beeps made participants report that streams of visual stimuli were segmented when they were in fact uninterrupted[2]. However, would *visual* strobes affect *auditory* time perception? If so, how?

To take a step back for a moment, let us ask: what *is* time perception? For the purposes of this experiment, time perception was defined as the estimation (independent of physical, external measures) of the duration of an event. Every philosopher and scientist throughout history has not defined time perception in such simple terms, however. Although physical realists such as Sir Isaac Newton described time as an almost concrete, physical entity, analogous to space, others, like Gottfried Leibniz or Immanuel Kant, argued that time is not 'real': it functions as a convenient mental tool [3] [4]

Certainly, our perception of time seems quite mutable. In certain high-adrenaline situations, people report that it seems as if time 'slows down'[5]. Conversely, within the experience of "flow" (immersion in pleasurable, interesting activity) participants systematically underestimate the amount of time that has passed[6]. Defining and understanding time perception is made more complex by the fact that our different modalities work together (and sometimes in opposition to one another) in order to give us a single time perception. When we snap our fingers, for instance, our brain tricks us into seeing, hearing, and feeling this as a single, synchronized event. However, we know from the way the auditory signal pathway versus the visual pathway works in the brain, that the brain's processing times for these two modalities are different. Thus, we actually 'hear' the snap before we 'see' it. Somehow, the brain synthesizes data across both modalities and makes the stimuli appear simultaneous[7]. Sometimes, however, one sensory system can trick another.

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The McGurk effect is just such a case. Here, visual information about another individual's lip movement that conflicts with actual auditory cues significantly transforms perception of the phoneme and what that person is saying[8]. The question still remained, however: would the visual cue of a strobe light cause the auditory system to misperceive how long an auditory cue lasted? With this question in mind, we designed our experiment.

RESULTS

The experiment did not confirm any statistically significant correlation between different strobe speeds and altered time perception. Using ratios of the actual time a music clip lasted to the time a participant estimated the clip to have lasted, each strobe light condition (fast, slow, constant light source, no light) was compared to each of the others. No significant differences in actual time/estimated time could be found across the different conditions. We ran the data through Matlab with the presumed null hypothesis (H_0) as zero difference between the perception of the two variables being compared and found the following results. The P-Values were very high, indicating that the null hypothesis could not be rejected, and thus the data was not statistically significant. We could not make any conclusions from our data, but could only know we could not reject the null hypothesis, and thus could not reject that there was no difference among the auditory percept of different visual stimuli rates.

Table 1

Comparison	Fast vs. Slow	Constant vs. No Light	Fast vs. Const.	Fast vs. No Light	Slow vs. Const.
H_0	0	0	0	0	0
P-Value	0.6007	0.8099	0.3243	0.8011	0.6358
Confidence Interval	(0.1577, 0.2649)	(-0.2535, 0.2007)	(-0.3085, 0.1077)	(-0.1963, 0.2507)	(-0.2509, 0.157)

DISCUSSION

Although the results were not statistically conclusive, it is possible to identify basic trends in preliminary data. On average, the no strobe condition produced an actual time/estimated time ratio of 1.07 (rounding to two decimal places). This means the actual time (the numerator) was higher than the estimated time (the denominator). The condition using a 200 Hz strobe (slow strobe condition) rendered a value of 1.02 (higher actual time than estimated time, but less so than the no strobe condition), and under the 400 Hz strobe (fast strobe condition) the value was 0.97 (i.e. participants overestimated the most for this condition). Thus, participants' time perception does appear to have slowed under this faster strobe condition. It appears that the no strobe condition produced time underestimates, and the faster the strobe rate, the longer participants tended to estimate the duration as having lasted. Not surprisingly, under constant light (which is the most common light stimuli), participants' time estimates were excellent, at a value of 1.00. If the outlier of subject 6 whose perceptions were extremely slow compared to the actual time is removed, the trends remain the same but the time perceptions are almost all faster than the actual time for all stimuli.

Originally, we thought people would become bored as the experiment progressed, but there is no evidence of data taken from later in each participant's trial being less reliable than earlier data. Data was manipulated to include only the first six stimuli the subjects saw, but the results were not significantly different and the trends remained the same, suggesting that 15 minutes was a good length for the experiment.

Although this experiment did not confirm our hypothesis that strobe speed would affect time perception due to identifiable confounds, further investigations are certainly merited. Several potential confounds which could have influenced the data are as follow:

Music selection:

- The timing on the music may not have been optimal (e.g. perhaps lighting changes affect very short or much longer periods of time than those measured).
- The pace of the music may not have been optimal for creating the desired effect (e.g. perhaps faster music renders people more vulnerable to the effect of strobes on time perception).
- The different musical pieces may have been an additional variable unintentionally: all music clips may not have been 'medium-paced' because they were subjectively chosen

Uncontrolled auditory cues:

- The strobe light made noise which may have contributed to the music.
- The experiment was not conducted in sound-proof room, so the participants could hear a timer beeping when recording was started and stopped. This may have biased the participant by giving him a better idea of our motive. The participants could hear people walking by and talking outside the room, this could have biased their times as well.

Other variables:

- Different people ran the experiment, and so may have turned the lights on and off at different times, cued up the music at different paces
- A manual stopwatch was used; therefore, there may have been a delay in auditory-motor responses.
- The room was not pitch black. The lighting could have biased the results because strobe did not have a large enough effect
- The experimenter was in the room with the participants, which prevented a realistic scenario. Although we were testing the stimuli rather than the scene, this still could have biased the participants' responses.
- Some participants did not realize exactly when they were supposed to knock, or even forgot to knock at all.
- The participants were all students. The experiment was run during a busy time of year, so most were removed from studying. They may have underestimated times more than they might have otherwise because they may have been distracted or wanted to return to their work.

Although the non-statistical examination of the preliminary results is encouraging, there is significant room for improvement in designing future studies. The use of some manner of automated timekeeping stopwatches to measure the participants' time estimates would reduce experimental error.

To assess whether the observation that higher strobe speeds led to participants estimating stimuli as having lasted longer, future studies should include longer and shorter music clips than those studied here. It may be possible to design an experiment that would help uncover whether time perception is categorical like the McGurk effect, as well as to assess whether contrasting theories of time perception as being best modeled as a linear or a logarithmic phenomenon are the most accurate[9]. Finally, future studies should certainly manipulate the music: music was kept as a constant in this experiment, but in the future slower and faster paces of music, as well as different types of music should be assessed for their effects on time estimation.

It is worthwhile to consider the value of understanding time perception better. Areas as diverse as television advertising, web page design, and mental health could all benefit from an increased knowledge of the underlying mechanisms of time perception. What if advertisers knew for exactly how long their customers would be willing to watch a television commercial before they became bored and flipped to a different channel[10]? What if companies knew just how long to keep their customers on hold without losing business[11] or what sorts of website designs to use to give the impression that pages are loading faster than they actually are[12]? On the other hand, what if psychiatrists could diagnose particular conditions based upon time-perception tests? Given evidence that certain mental illnesses are characterized by differences in how quickly they perceive events[13] [14] [15], a more precise understanding of the factors that underlie time perception might even motivate better diagnostic tests. Although time perception has a wide array of different applications, some a far cry from watching strobe lights and listening to clips of music, by studying the effect of strobe speed on auditory time estimates, we might uncover new and valuable understandings of the basic nature of time perception.

METHODS

Experimental Set-up. A chair was placed in the corner of a dark room. Experimenter 1 sat outside the room keeping time, while Experimenter 2 sat inside the room controlling strobe rate/music. Both the speakers and strobe light were set up facing the subject. All music was played from a laptop computer. A spreadsheet was made containing random orders of music for 10 trials.

Experimental Procedure. Participants were first shown an information sheet (shown in Appendix A) with directions and warning of strobe. They were asked to give all time-keeping devices to the experimenter and asked NOT to count when estimating the time as well as told to pay attention to the auditory stimuli versus the visual stimuli (but asked to keep eyes open). The subject sat down on a chair in the corner facing the wall, close enough to the door to knock comfortably. Experimenter 2 started the music clip and the subject knocked on the door once to indicate he heard the music starting. If there was no visual stimulus, experimenter 2 informed the subject that there was no visual stimulus for this trial to avoid misinterpretation of a mistake in the procedure. When the music clip ended, the subjects knocked on the door once to start reproducing the time length of the music clip and experimenter 1 started the timer from outside the door. The subject knocked on the door twice to indicate the end of the time reproduction when he felt the same amount of time as the length of the music clip had passed by and experimenter 1 stopped the timer. These steps were repeated twelve times during twelve randomly ordered music clips (out of the total twenty-four). The visual stimuli were presented with the auditory stimuli. The visual stimuli were presented in rotation of no stimuli, 200 Hz, 400 Hz, and perceptually constant stimuli (17,000 Hz).

Motivation for Experimental Procedure. The music was chosen to be medium paced, instrumental, and esoteric to minimize cues on which the participant might base time estimation. The clips were of 10, 15, 20, or 30 seconds, in order to avoid habituation to the length of the music. The order the music was presented was chosen at random prior to beginning experimentation to avoid bias. The strobe speeds of fast, slow, no strobe, and constant were chosen not only for convenience but also because we wished to look for large differences (between very slow – 400 Hz – and very fast – 200 Hz), as opposed to small differences such as 25 Hz. With larger differences, we hoped to quickly eliminate certain relationships (i.e. if there was no distinct difference between constant and fast, we would not pursue that question further) in order to set the stage for later experiments.

ACKNOWLEDGEMENTS
The authors thank Professor Sinha for his guidance in experimental and data analysis design and Professor David Eagleman for his inspiration and guidance in experimental design, and the MIT Edgerton Center for the use of its equipment.

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