The Effect of Five Factors on Elapsed Time Perception in a Visual Medium

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Abstract

We consider the effects of five forms of stimuli on perception of elapsed time while watching short, animated videos in a 2^{5-1} fractional-factorial model. Similar to what consumers might experience in a digital waiting environment, the videos involve simple animated loops that repeat multiple times. The videos differ on five factors alone: the presence of an auditory chime, the use of color, contrast between the background and the foreground animation, the length of the video, and the periodicity of the loops. For each factor, half of the videos produced had the factor at its low level and half at its high level. Participants were shown one of the treatments and afterward asked to estimate the length of the video (n = 271). Four of five factors were found to have a statistically significant effect on perceived video length, along with two interactions.

Keywords: time perception, fractional-factorial design, visual medium

1. Introduction

The way in which humans perceive the passage of time has long intrigued researchers across multiple domains. In one of the earliest publications on the topic, Jurkovich et al. (1987) found that paramedics in the field overestimated elapsed time for shorter tasks and underestimated elapsed time on longer tasks. More recently, two studies addressed the impacts of various colors and filler images on perceived waiting time in an online environment (Gorn et al., 2004; Lee et al., 2012), while two others manipulated auditory input to assess its impact on time perception while playing video games (Cassidy & MacDonald, 2010; Sanders & Cairns, 2010). Time perception has been studied in the medical field as well, with Schneider et al. (2011) testing the use of virtual reality immersion to hopefully minimize the perceived time of chemotherapy treatments.

In addition to these results, Eagleman (2008) noted how "…perceived durations can be distorted by… an oddball in a sequence." These findings collectively point to the potential impact of sound, color, length of exposure, and changing patterns on our ability as humans to accurately judge the passage of time. The present study was designed to consider these effects jointly in a controlled digital setting.

Researchers were interested in assessing the impact of five factors specifically on participants' perceptions of elapsed time while watching a brief, repetitive animation. Those factors included the presence of an audible chime, the use of color, the degree of contrast between the foreground and background, the length of the video, and the regularity of a pause between animated loops in the video. The remainder of this paper details the methods used in section two, provides analysis of the study results in section three, and concludes with a brief discussion in section four.

2. Methods

Each of the five factors mentioned previously was studied at two levels, the values of which are specified in Table 1. Such a setup, with five factors at two levels each, is known as a 2^5 full factorial design, assuming all thirty-two treatment combinations are run. However, this design was judged unfeasible due to time constraints and sampling availability. Instead, sixteen well-chosen treatments were selected, leading to a 2^{5-1} fractional-factorial design, and analysis proceeded using this "half-replicate" strategy (Berger et al., 2018).

Factor	Low Level	High Level
A: Audio	No sound	Audible chime at animation start
B: Color	Grayscale	Color
C: Contrast	Foreground and background same shade	Foreground and background different shades
D: Length	24 seconds	34.667 seconds
E: Periodicity	Regular pause of 2.667 seconds between all animation loops	Random, differing pause length between each animation loop

Table 1: The two levels used for each factor in the study.

2.1. Fractional-Factorial Experimental Design

What follows is a brief synopsis of issues related to the implementation of a fractional-factorial design. For greater detail, we direct the interested reader to Part III of Berger et al. (2018).

In choosing to employ only half of the available treatment combinations, we accept specific limitations. Rather than being able to estimate all effects individually, we create alias pairs, which are pairs of effects that are only estimable in combination with each other, either via addition or subtraction, rather than alone. With a 2^5 design, there are thirty-one effects, but by implementing a 2^{5-1} design, we forfeit the ability to estimate one effect completely while computing the remaining thirty as fifteen alias pairs.

On the surface, this seems like a large concession, but in many practical applications it is not at all. Consider that with five factors, sixteen of the thirty-one effects are three-way, four-way, or five-way interactions, and these are often statistically insignificant (Berger et al., 2018). There are five main effects and ten two-way interactions, and if we choose which sixteen treatments are included in the experiment smartly, we can maintain the ability to estimate these fifteen effects, given the important assumption that all three-way and higher order interaction effects are negligible.

A + BCDE	*B + ACDE*	*C + ABDE*	*D + ABCE*	*E + ABCD*
AB + CDE	*AC + BDE*	*AD + BCE*	*AE + BCD*	*BC + ADE*
BD + ACE	*BE + ACD*	*CD + ABE*	*CE + ABD*	*DE + ABC*

Table 2: Alias pairs, with factor A audio, factor B color, factor C contrast, factor D length, and factor E periodicity.

In fact, by sacrificing the five-way interaction effect, which is highly unlikely to be meaningful in any realistic scenario, we obtain the alias pairs shown in Table 2 and run the sixteen treatments listed using Yates' notation in Table 3. To clarify Table 2, note that, for example, *ABC* represents the three-way interaction effect between factors A, B, and C, while *E* represents the main effect of factor E. We observe that all main effects are paired with four-way interaction effects, and if all interactions of higher order than two are insignificant, as assumed, then an estimate of these five alias pairs is, in actuality, an estimate of the five main effects. Similar logic holds for the estimation of the two-way interaction effects, which are all paired with three-way interactions.

1	*ab*	*ac*	*ad*	*ae*	*bc*	*bd*	*be*
cd	*ce*	*de*	*abcd*	*abce*	*abde*	*acde*	*bcde*

Table 3: The list of treatments run in the experiment, given in Yates' notation, so that the presence of a letter indicates a factor at its high level, the absence of a letter indicates a factor at its low level, and the *1* signifies the treatment with all factors at their low level.

Note the differences between factors, effects, and treatments in our notation. Non-italicized capital letters represent factors, italicized capital letters indicate effects, and lowercase letters denote treatment combinations. One treatment chosen to be included was *ab*; this treatment was a video with an audible chime and full color (the high levels of factors A and B) but with no foreground-background contrast, the shorter length of 24 seconds, and a regular interval between animations (the low levels of factors C, D, and E). One might notice that all treatments run are those containing an even number of letters (with the treatment *1* including 0 letters). This is not an accident, but a natural consequence of our design choice. Additionally, each of the five factors appears at its high level in eight treatments and its low level in eight treatments, so that we maintain balance in assessing each factor's impact.

2.2 Data Collection

Videos, which are available as supplementary material for this article, were created for each of the sixteen treatments chosen. Each video includes a stationary gray sphere floating in the center of the screen on a solid, dark background. At various intervals, an icosahedron appears to grow out of the sphere, rotating as it grows, and then diminishes back into the sphere again. This entire animation loop lasts 2.667 seconds and repeats following a brief pause. When color is used (the high level of factor B), it is applied only to this icosahedron, with various colors on different locations of the polygon, so that, in theory, the shape stands out more prominently when it appears in color.

After receiving IRB approval, participants were obtained from sixteen different sections of introductory mathematics and statistics courses at Colorado Mesa University over a three-week period during the Spring 2021 semester. A researcher attended the start of a chosen class meeting, read the same script each time, and obtained written informed consent from any willing participants. The script included informing students that they would be shown a short video, that there were no anticipated potential negative consequences of viewing the video, and that following the video a single question would be asked of them. Participants were not told ahead of time that they would be asked to estimate the video's length, as that would have changed their awareness of the passage of time. Videos were shown using each classroom's projector and audio system with artificial lighting off and shades drawn to minimize distractions and make testing conditions as homogeneous as possible.

3. Results

Sample sizes ranged from ten to twenty-five, with a total of 271 participants, for an average sample size per treatment of just under seventeen people. The variable of interest was the difference between participants' estimates and the true video length. Its distribution across all treatments is shown in Figure 1, where we see that participants underestimate time on average, irrespective of which treatment conditions they are given; the median estimate is a full nine seconds short of the truth, and the 75th percentile is an estimate that is still short by four seconds.

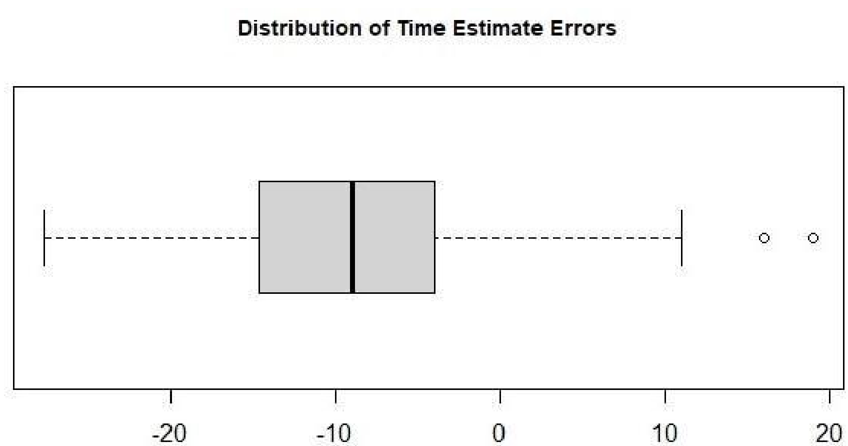

Figure 1: A boxplot of the differences between participants' estimates of video length and their true lengths, in seconds.

Armed with this understanding that people tend to underestimate the passage of time, at least under these experimental conditions, we can shift our focus to the impact of each factor on those estimates. Analysis of the responses revealed no violations of the assumptions of constant variance and normality required for significance testing in a linear model. As such, we began by modeling time estimation error as a function of all five main effects and all ten two-way interactions.

Unsurprisingly, many of the fifteen estimated effects were insignificant, with p-values greater than the standard 0.05 threshold. Using backwards elimination, we then removed one variable at a time, starting with the least significant, and re-computed the regression coefficients until we obtained the optimal model, judged so by mean squared error and the Akaike Information Criterion, or AIC (Akaike, 1973). This model, with coefficients provided in Table 4, offers multiple noteworthy results.

Coefficient	**Estimate**
Intercept	-4.299 (.0039)
Audio	-3.113 (.0455)
Color	2.275 (.0319)
Length	-5.802 (.0002)
Periodicity	-5.306 (.0038)
Audio:Periodicity	5.074 (.0156)
Length:Periodicity	4.219 (.0453)

Table 4: Coefficient estimates from the final model, with p-values given in parentheses.

First, any term not included in this final model had an insignificant impact on time estimation. In fact, no term removed at any step in the process had a p-value smaller than 0.24. Thus, the degree of contrast between the foreground and background in the video did not meaningfully impact participants' estimates of video length. Additionally, each coefficient estimate acts like an on/off switch, being switched "on," so to speak, when a factor is at its high level and "off" when the factor is at its low level. For interaction terms, this value represents the effect of having both factors at their high levels.

Ignoring the intercept, we can see that three effects negatively impact time estimation, while three other effects are positive. Consider first the color effect. In this experiment, the effect of producing a video with a colored icosahedron as opposed to one that matched the gray shade of the sphere from which it erupted was to increase participants' estimate of elapsed time by 2.275 seconds, on average. With a p-value of 0.0319, this is a substantial finding at the 0.05 significance level.

The interpretation of the other three significant main effects is less straightforward, as each is involved in an interaction term as well. It is clear that video length is the most significant factor, due to its p-value of nearly 0, but when we consider the interaction between length and periodicity, we find that random periodicity mitigates the effect of lengthening the video. Stated another way, if the breaks between animation loops are held constant at two and two-thirds seconds, we expect time estimates to be low by about 5.8 seconds *more* for the long video than for the short video. Recall that estimates were too low in general, but this means that participants' estimates of elapsed time are significantly worse (farther from the truth on the short side) for the longer video. However, if the breaks between animation loops are random, we observe that the difference in estimation errors between the short and long videos is much less noticeable, at -5.802 + 4.219 = -1.583 seconds, on average. This interaction effect can be seen in Figure 2, where the mean time estimation error is plotted as a function of video length and periodicity.

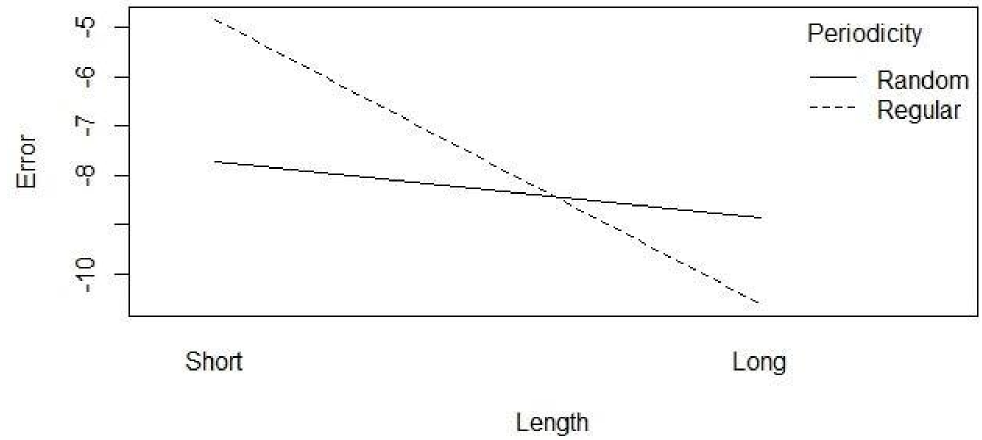

Figure 2: Mean time estimation error by video length and periodicity.

An even more striking interaction exists between the audio and periodicity factors. As can be seen in Figure 3, the effect of adding an audible chime at the beginning of the animation loop differs depending on whether the break between loops is regular or random. With regular breaks, adding an audible chime appears to decrease perception of elapsed time, while with irregular, random breaks the exact opposite is true. Our model predicts a decreased time estimate of just over three seconds when a chime is added to the video with regular breaks and an *increased* time estimate of nearly two seconds when a chime is added to the video with random breaks.

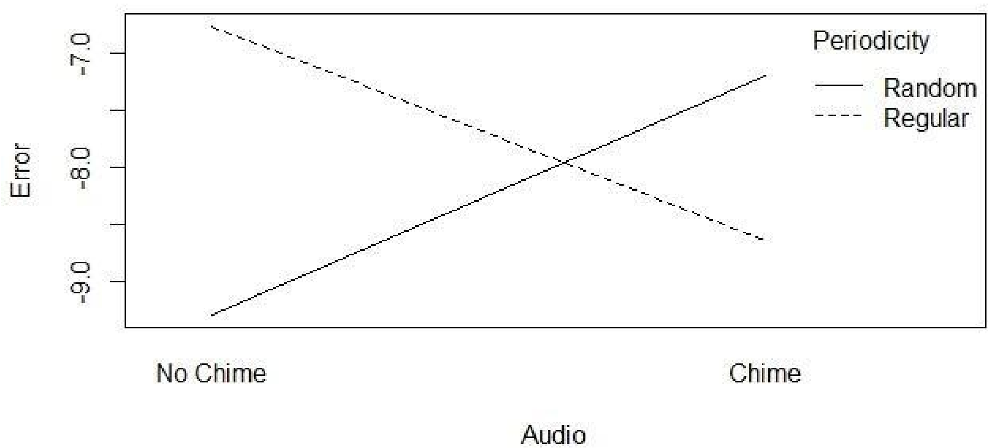

Figure 3: Mean time estimation error by audio presence and periodicity.

Periodicity is likely the most complex factor to discuss, as we have already seen that its impact depends on both audio and length. Using the last three rows of Table 4, we can calculate the effect of changing from regular to random intervals between animation loops for each of the four combinations of the levels of audio and length. Given no chime in the shorter video, the effect of random breaks is to decrease perceived elapsed time by more than five seconds, on average. If a chime is added to the short video, however, periodicity has almost no impact on time perception, with a calculated effect smaller than a quarter-second in the negative direction. For the longer video with no chime, a random break leads to an average decrease in perceived time of just over a second, and finally, we see the opposite effect for the longer video with a chime, where random breaks are predicted to increase perceived video length by nearly four seconds as compared to regular breaks.

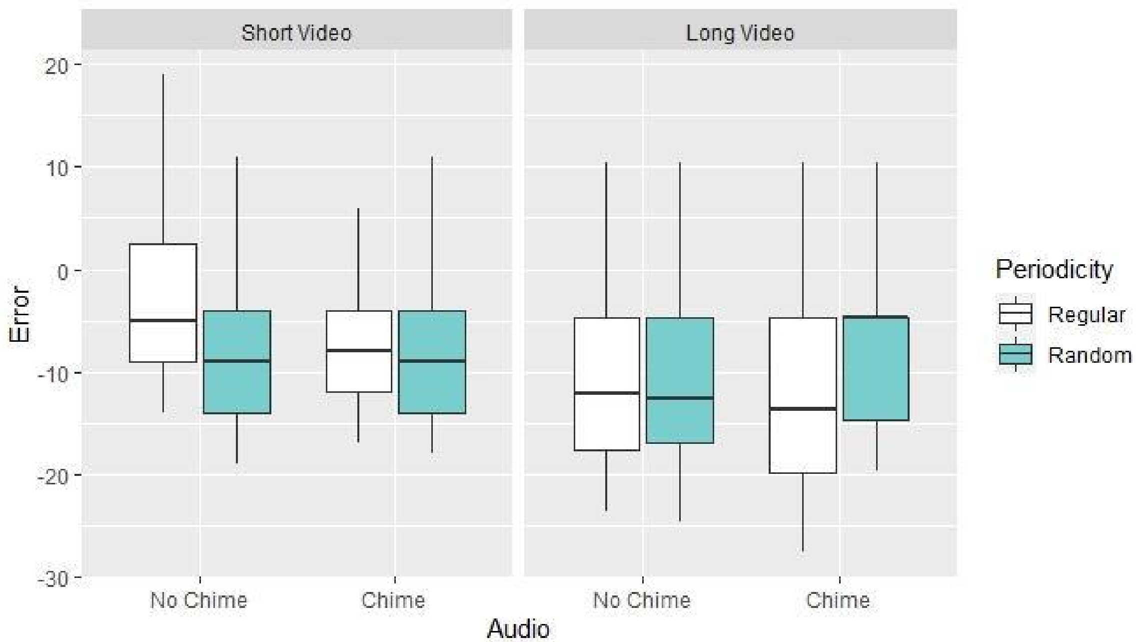

Figure 4: The distribution of time estimation errors separated by audio, length, and periodicity levels.

All of this is summarized visually in Figure 4, where we see box plots for every combination of the three factors we have been discussing. We observe the negative impact of random periodicity with no chime in the short video, the negligible impact of periodicity in the middle two cases, and its positive impact with a chime in the long video, where the median for the random-break distribution is approximately equal to the 75th percentile of the regular-break distribution. Additionally, we can see from Figure 4 that the most accurate estimates of elapsed time, on average, came from the short video with no chime and regular intervals between animation loops. Though color is not considered in this graphic, we know from Table 4 that these estimates improve even further (meaning that the errors are closer to 0, on average) if this video is rendered with a colored icosahedron.

4. Conclusions

The limitations of this study should be noted. Beyond the fact that the sample consisted only of college students taking introductory mathematics or statistics courses, practical factors precluded the implementation of absolutely homogeneous experimental conditions. Samples were obtained in multiple campus locations, and though the available technology from classroom to classroom is very similar, the lighting, audio systems, and room configurations should not be assumed to be identical. Future research using only one testing location could help to alleviate concern over potential confounding from any of these factors.

Additionally, conclusions should not be extrapolated beyond the scope of the experimental conditions. Though video length was found to have a significant impact on time perception, we cannot conclude anything about the differences for videos lasting between two and three minutes, for example. Likewise, different choices of periodicity, contrast, and the video itself could lead to varying outcomes.

With this said, the significance of the results obtained should not be understated. We have observed not only that individuals regularly underestimate the passage of time when exposed to a visual medium, but that their perception of elapsed time can be impacted by sound, color, and the degree of consistency in the video itself. The most intriguing result will be in the eye of the beholder, but the authors find the degree of interaction between the audio, length, and periodicity factors to be particularly noteworthy. The effect of adding an audible chime to the videos was found to be reversed depending on whether breaks between animation loops were regular or random, which would seem to point to the complex nature of the way the human brain processes audio and visual cues simultaneously. Similarly, the effects of periodicity and length were each mitigated by the presence of the high level of the other. Future research might be interested in whether these patterns continue with videos that are longer or whose lengths are more disparate. Of course, there are likely a number of other factors that could be introduced and which might also impact the perception of elapsed time. The current research provides a small window into a vast spectrum of possibilities.

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