AN ABSTRACT OF THE THESIS OF

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Abstract approved:____

Dr. Lawrence Ryan

Studying human's ability to estimate temporal durations could lead to a greater understanding of our cognitive abilities as well as the processes that underlie temporal estimation. It has been shown through previous research that time and number may be interconnected cognitively and that the magnitude of one may alter the perception of the other, which could be tested by using numerical anchors. I proposed that larger single digit anchors will cause overestimation of duration and smaller single digit anchors will cause underestimation of duration in both the millisecond and second ranges. A total of six experiments were completed testing the idea that numbers can anchor duration judgments. The first two experiments tested the ability of numbers to alter time perceptions in the millisecond range. The last four experiments tested the ability of numbers to alter time perceptions in the second range. Overall only durations lasting for a matter of milliseconds showed significant results implying that numbers could alter the perception of time in the millisecond range. These experiments could further support the idea that numbers can alter the perception of millisecond timing. These experiments do not support the idea that numbers can alter the perception of second timing.

Keywords: Temporal perception, numerical perception, interval timing, millisecond timing, anchoring.

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Numerical Effects on Timing System Pathways

By

Samantha K. Steiner

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Samantha K. Steiner, Author

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Numerical Effects on Timing System Pathways.

1. Introduction

The ability to estimate durations of time is essential for making rational decisions, accurate memories, associations of events, and coordination of movements in response to stimuli. Without being able to make temporal estimations, we wouldn't be able to make judgments about oncoming velocities, or even be able to coordinate our movements enough to flee from danger. Studying human's ability to estimate temporal durations could lead to a greater understanding of our cognitive abilities as well as the processes that underlie temporal estimation.

Organisms appear to have evolved different systems to deal with time. The three timing systems are circadian timing, interval timing, and millisecond timing. Circadian timing works over the range of a twenty four hour light-dark cycle and controls behaviors such as appetite and sleep-wake cycle. Interval timing works in the seconds to minutes range and is involved in decision making and foraging. Millisecond timing works in the range of milliseconds and is used for motor control and language.

Circadian, interval, and millisecond timing may involve different neural mechanisms (Buhusi et al. 2005). The circadian clock coordinates metabolic and behavioral rhythms through a network of transcriptional feedback loops, activated by light input and social information. In mammals the circadian clock is located in the suprachiasmatic nucleus of the hypothalamus. It is currently thought that millisecond timing uses long-term depression and long-term potentiation, which are the weakening and strengthening of neural synapses, in the cerebellum to process millisecond durations. The least well understood is interval timing. One neural hypothesis suggests that interval timing uses long-term depression and long-term potentiation in corticostriatal circuits and intact striatum dopamine neurons to process second durations. Sometimes both the striatum and cerebellum would be activated in interval timing as well.

Fraisse (1963) originally proposed that there are two timing systems with different properties for millisecond and second timing. There has been experimental support for the idea for two timing systems (Ulbrich et al. 2007). For example, one recent experiment indicated that temporal reproductions of longer and shorter intervals used different processes. This experiment compared the reproductions of three to five second long intervals, termed longer intervals, to the reproductions of one to two second long intervals, termed shorter intervals. The subjects would either hear a tone or see a square on the screen for a certain duration, and then the subjects were asked to replicate the duration of the stimulus using another stimulus, a tone if the previous stimulus was a tone or a square if the previous stimulus was a square. The experiment showed that shorter intervals had no effects of modality or the use of working memory, which supports Fraisse's idea that shorter durations are perceived as a unit and do not use working memory. The experiment also showed that longer intervals were strongly influenced by cognitive processes, supporting Fraisse's idea that longer durations are estimated and use working memory.

However results of other research have not been consistent with the idea that there are separate timing systems. For instance, Ramsayer (2005) conducted experiments to test the idea that there were two separate timing mechanisms, one for processing millisecond information and another for processing longer durations. All four experiments used a dual task approach. The experiments all used a timing task as the primary task but differed on the secondary task. The first experiment used mental arithmetic as the secondary task. The second experiment used a memory search task as the secondary task. The third experiment used a visuospatial memory task as the secondary task. The fourth experiment used a loudness manipulation task as the secondary task. The subjects would have to complete both tasks at the same time during each experiment. It was thought that the secondary tasks would interfere with the ability to time longer intervals and not interfere with the ability to time millisecond long intervals, as timing longer intervals use cognitive processing and millisecond long intervals use automatic processing. It was shown that in experiments 1 and 4 the secondary task caused interference with the timing of both millisecond long durations and longer durations. The secondary task caused no interference in the timing of either duration in experiments 2 and 3. As a result of this, it is argued that there are not two distinct timing systems. Although there has been some evidence that has refuted the idea that there are separate timing systems there is still more evidence in support of this idea, and therefore this hypothesis is still being actively researched.

Many different theories have been proposed as ways to explain how animals represent the different timing systems. One important theory is the scalar timing theory, which has been primarily used to account for timing in the seconds to minutes range, but theoretically it can be used for all scales of time (Church 1997). Both human and animal timing experimental data can be explained using scalar timing theory. This theory proposes that a neural pacemaker-accumulator system is used for generating time signals. In addition to temporal estimation, both number and magnitude could be estimated using the scalar timing theory. The pacemaker is an oscillator that emits pulses in time. The accumulator is a counter that temporarily stores and sums the pulses that the pacemaker emits. The accumulator can only store the total number of pulses temporarily. The value in the accumulator is encoded to reference memory for longer storage and retrieval (Buhusi et al. 2005). The temporal estimation is made by the ratio between the current subjective time, which is currently being held in the accumulator, compared to the clock reading, which is the number of pulses currently stored in the reference memory.

A recent functional MRI study has attempted to show which brain regions are activated during the interval encoding stage of scalar timing theory. (Harrington et al. 2004)As it was important to ensure that intervals were encoded in each trial, Harrington et al. (2004) implemented a time perception task that consisted of two standard intervals that were randomly presented. Functional MRIs were taken as the subjects encoded the intervals, and these images were then analyzed. This study showed that regions of the basal ganglia, cerebellum, and cerebral cortex were activated during interval encoding. Only some of these regions, including the right inferior parietal cortex, are correlated with behavioral measures of time discrimination.

The right inferior parietal lobe has been implicated more generally in magnitude estimation of quantity, time and space (Walsh 2003). It has already been shown that the right inferior parietal cortex is important for time perception (Harrington et al. 2004). It has also been shown that the right parietal cortex is activated in comparison and estimation number processes. Walsh (2003) proposes that time and number use common magnitude mechanisms that may be located in the parietal cortex. This means that the magnitude of a number may influence the magnitude of the time judgment.

The association of the magnitude estimations of temporal discrimination and numerical comparison may mean that what affects one judgment (magnitude) should affect the other judgment (duration). The ability of a number to affect judgments is called the anchoring effect, where the perceived number is called an anchor (Janiszewski et al. 2008). The anchoring effect could be used to test if the magnitude estimation system is used in time perception.

In a recent psychophysical discrimination task experiment rats showed the ability to record number and time simultaneously (Meck et al. 1983). In order to explain these findings a dual mode model has been proposed which contains a clock, memory, and decision processes. The dual mode model is similar to the scalar theory of time except the dual mode model proposes that there are two accumulators instead of just the one proposed in scalar timing theory. One accumulator would be a time accumulator, which would have run and stop modes. The other accumulator would be a clock accumulator, which would operate in an event mode. This model has been supported through neuroimaging and electrophysiological studies which suggested that the basal ganglia, prefrontal cortex, and posterior parietal cortex are involved in number representation as well as in interval timing (Buhusi et al. 2005; Hinton et al. 2004). The ability of animals to record number and time simultaneously has also been supported through the aforementioned functional MRI study. The functional MRI experiment showed that the parietal cortex was activated in both number manipulation as well as interval encoding (Harrington et. al 2004).

Knowing that time and number perception can both be recorded simultaneously and may use the same neural pathways for encoding, it can be theorized that number perception can alter time perception. It has been shown that the increasing duration of a stimulus can cause the overestimation of numerosity, which shows that the perception of one element has an impact on the other (Allik et al. 1993). It is possible that an increased number value could cause the overestimation of duration and the decreased number value could cause the underestimation of duration, just as the increased duration can cause overestimation of numerosity. It has already been shown by Oliveri et al. (2008) that numbers can influence time perception in millisecond timing. In their experiment, subjects judged whether a digit, also called a test cue, had been presented for a longer or shorter duration than a reference digit. The reference digit was always shown first in this experiment. The reference digit was always the number 5 and always remained on the screen for 300 milliseconds. The test cue was shown after the reference digit. The test cue was either "1", "5", or "9". The test cue remained on the screen for either 250, 260, 270, 280, 290, 300, 310, 320, 330, 340, or 350 milliseconds. The duration of the test cue was randomized across the trials, with five presentations of each number. They also ran two control experiments. One control experiment used double digit numbers, such as 11, 15, or 19. The other control experiment used letters, such as M, I, or Q. The letter control experiment showed that just changing the display to be timed does not affect the perception of time. The double digit control experiment showed that double digit numbers do affect the perception of time. This supports the idea that time perception can be altered based on the numerical magnitude, meaning larger digits bias estimations toward longer durations and smaller digits bias estimations toward shorter durations.

The ability of numerical magnitude to influence time perception has also been shown in another experiment by Vicario (2007). This experiment used a perceptual time bisection task where the subjects were asked to reproduce half of the sample display's duration with a test cue, and imaginative time bisection task, where the subjects were asked to reproduce half of the sample display's duration with an imaginary mental timer. This experiment showed that numbers altered time judgments in imaginative time bisection tasks and not in perceptual time bisection tasks, which may mean that time imagination and time perception are differently affected by numerical magnitudes.

While it has already been shown that increased number value can cause subjects to overestimate duration and decreased number values can cause underestimation of duration in millisecond timing, this phenomenon has not been shown in second timing. If millisecond and second timing use different processes, as proposed by Buhusi et al. (2005), then they may be subject to different interactions with number. I am going to further study this phenomenon by running experiments testing the impact of numbers on duration within second timing, as well as replicate the experiment done by Oliveri et al.(2008). These experiments will be using the anchoring effect to test the effect of numerical magnitude on time perception. I expect that larger single digits will cause overestimation of duration and smaller single digits will cause underestimation of duration in both the millisecond and second ranges.

2. Materials and Methods

2.1 Subjects

All 104 participants were volunteers, who were taking a psychology class at Oregon State University. The volunteers were not paid to participate in our study; instead they were given extra credit in the psychology class they were taking that term. Participation conditions were approved by the Oregon State University Institutional Review Board and met all current ethical guidelines for the use of human participants.

2.2 Materials

All of the following experiments utilized four different computers and seven different computer programs written and modified by Dr. Ryan and Brandon High.

Experiments 1 through 4 used two Pentium computers running DOS. These experiments utilized computer programs written and modified by Dr. Ryan, who used the programming language C. These computer programs were used because they were written for experiments using durations in the seconds range, and experiments 1 through 4 were also using durations in the seconds range.

The remaining experiments used newer computers running Windows XP. These experiments utilized computer programs written and modified by both Dr. Ryan and Brandon High, who used the Tscope experiment programming library for the C programming language. Experiments 5 and 6 were using durations in the milliseconds range. Programs written for DOS could not make accurate millisecond long durations, but programs utilizing Tscope could make accurate millisecond long durations.

2.3 Experiments

All experiments tested the idea that numbers can anchor duration judgments. Small numbers should shorten duration judgments and larger numbers should lengthen duration judgments. Letters of a similar appearance were used as a control for the different displays to be tested. Experiments used either a reproduction or a comparison task. In the reproduction task students would time a sample condition and then after a short delay they would reproduce that duration with a replication condition. In the comparison task students would compare the comparison condition's duration with that of the sample condition and state whether or not the comparison condition's duration was longer than that of the sample condition. Each number or letter was displayed on the computer screen for a certain duration of time. The subjects would see the numbers and letters, but the duration of each would be unknown. We measured the subject's duration reproduction to determine the effect of numbers and letters on time perception.

Before the subjects went into the experiment, we instructed them on how to do the experiment, as well as got their informed consent. We also asked them to not count out the duration of the symbol, as we were testing their perceptions, not their ability to time via counting. The subject would then sit at a computer. The first screen the subjects saw was an instruction screen, explaining what buttons to press to do the different tasks in the experiment. After the subjects read the instructions they would then start the trials. At the end of the experiment we would debrief the participants by explaining the experiment and our expectations to each subject.

The first two experiments deal with timing in the millisecond range whereas the last four experiments deal with timing in the second range. We thought that it was important to test both time ranges, as to discern any differences in the ranges.

2.3.1 Experiment 1

This experiment is a replication of the time perception experiment done by Oliveri et al. (2008) This experiment utilized a between subject design of letters versus numbers. There were two conditions in this experiment. The first experimental condition dealt with only numbers, whereas the control condition of this experiment dealt only with letters. In both versions there was a sample symbol that lasted for a set duration and comparison symbols that lasted for varying durations.

The duration for the sample display was 300 milliseconds. The durations for the comparison display were 250 milliseconds, 260 milliseconds, 270 milliseconds, 280 milliseconds, 290 milliseconds, 300 milliseconds, 310 milliseconds, 320 milliseconds, 330 milliseconds, 340 milliseconds, and 350 milliseconds. The sample number display was 5. The comparison number displays were 1, 5, and 9. The sample letter display was M. The comparison letter displays were I, M and Q. Each comparison number display and comparison letter display was paired with a duration in each version. This experiment used a blocked design. Each number or letter were separated into its own block, thus each version has three blocks. These pairings resulted in 33 sample conditions for each version of this experiment as seen in table 1.1 and 1.2 below.

Presentation order was counter balanced. The even numbered subjects saw block one first, block two second, and block three last. For each version, the odd numbered subjects would see block three first, block two second, and block one last. The sample conditions for each block were displayed a total of five times. Each sample condition within each block was displayed randomly throughout that block. At the end of each trial the subject would be asked if the comparison symbol appeared on the screen for a longer or shorter duration than the sample symbol. This comparison was done with either the number 1, 5, or 9 for the number version and either the letter I, M, or Q for the letter version.

Experiment 1 Sample Conditions, Number Version				
Block	Sample Condition	Sample Display	Comparison Display	Duration
1	1	5	1	250
1	2	5	1	260
1	3	5	1	270
1	4	5	1	280
1	5	5	1	290
1	6	5	1	300
1	7	5	1	310
1	8	5	1	320
1	9	5	1	330
1	10	5	1	340
1	11	5	1	350
2	12	5	5	250
2	13	5	5	260
2	14	5	5	270
2	15	5	5	280
2	16	5	5	290
2	17	5	5	300
2	18	5	5	310
2	19	5	5	320
2	20	5	5	330
2	21	5	5	340
2	22	5	5	350
3	23	5	9	250
3	24	5	9	260
3	25	5	9	270
3	26	5	9	280
3	27	5	9	290
3	28	5	9	300
3	29	5	9	310
3	30	5	9	320
3	31	5	9	330
3	32	5	9	340
3	33	5	9	350
Sample Size = 17				

Table 1.1

Experiment 1 Sample Conditions, Letter Version				
Block	Sample Condition	Sample Display	Comparison Display	Duration
1	1	M	I	250
1	2	M	I	260
1	3	M	I	270
1	4	M	I	280
1	5	M	I	290
1	6	M	I	300
1	7	M	I	310
1	8	M	I	320
1	9	M	I	330
1	10	M	I	340
1	11	M	I	350
2	12	M	M	250
2	13	M	M	260
2	14	M	M	270
2	15	M	M	280
2	16	M	M	290
2	17	M	M	300
2	18	M	M	310
2	19	M	M	320
2	20	M	M	330
2	21	M	M	340
2	22	M	M	350
3	23	M	Q	250
3	24	M	Q	260
3	25	M	Q	270
3	26	M	Q	280
3	27	M	Q	290
3	28	M	Q	300
3	29	M	Q	310
3	30	M	Q	320
3	31	M	Q	330
3	32	M	Q	340
3	33	M	Q	350
Sample Size = 17				

Table 1.2

2.3.2 Experiment 2

As the sample duration must be stored in memory and the comparison duration is currently perceived, the numerical anchors may differently affect the sample or the comparison displays, which is why it is important to test the effect of numerical anchors on both the sample and the comparison displays. The Oliveri et al. (2008) experiment only examined the effect of anchor on the comparison display. This experiment is complementary to the number version of experiment 1, except in this experiment the sample display varied and the comparison display was fixed. (Reference table 2.1 below for this experiment's sample conditions.)

Presentation order was counter balanced. The even numbered subjects would see block one first, block two second, and block three last. The odd numbered subjects would see block three first, block two second, and block one last. The sample conditions for each block were displayed a total of five times. Each sample condition within each block was displayed randomly throughout that block. At the end of each trial the subject would be asked if the comparison symbol appeared on the screen for a longer or shorter duration than the sample symbol. This comparison was done with the number 5.

Experiment 2 Sample Conditions				
Block	Sample Condition	Sample Display	Comparison Display	Duration
1	1	1	5	250
1	2	1	5	260
1	3	1	5	270
1	4	1	5	280
1	5	1	5	290
1	6	1	5	300
1	7	1	5	310
1	8	1	5	320
1	9	1	5	330
1	10	1	5	340
1	11	1	5	350
2	12	5	5	250
2	13	5	5	260
2	14	5	5	270
2	15	5	5	280
2	16	5	5	290
2	17	5	5	300
2	18	5	5	310
2	19	5	5	320
2	20	5	5	330
2	21	5	5	340
2	22	5	5	350
3	23	9	5	250
3	24	9	5	260
3	25	9	5	270
3	26	9	5	280
3	27	9	5	290
3	28	9	5	300
3	29	9	5	310
3	30	9	5	320
3	31	9	5	330
3	32	9	5	340
3	33	9	5	350
Sample Size = 11				

Table 2.1

2.3.3 Experiment 3

This experiment tests the effect of numerical anchors on time judgments in the second range. The durations used in this experiment were 5.5 seconds and 11.5 seconds. The numbers used were 3, 12, and 21. The letters used were B, IJ, and TI. Each number and letter was paired with a duration. These pairings resulted in a total of 12 sample conditions, as seen in Table 3.1 below.

Experiment 3 Sample Conditions			
Sample condition number	Sample Display	Replication Display	Duration (seconds)
1	12	3	5.5
2	12	3	11.5
3	12	12	5.5
4	12	12	11.5
5	12	21	5.5
6	12	21	11.5
7	12	B	5.5
8	12	B	11.5
9	12	IJ	5.5
10	12	IJ	11.5
11	12	TI	5.5
12	12	TI	11.5
Sample Size = 16			

Table 3.1

For each trial the subject would see either one of the sample conditions, as seen in table 3.1 above. At the end of a trial, the subject would be asked to reproduce the symbol’s duration. Each trial consisted of one sample condition. Each sample condition was displayed a total of eight times throughout the experiment. All of the sample conditions were displayed in a random order throughout the experiment.

2.3.4 Experiment 4

This experiment is similar to experiment 3 except the anchors are presented in the sample display instead of the replication display because the numerical anchors may differently affect the sample or the comparison displays, as the sample duration must be stored in memory and the comparison duration is currently perceived. The durations used in this experiment were 5.5 seconds and 11.5 seconds. The numbers used were 3, 12, and 21. The letters used were B, IJ, and TI. Each number and letter was paired with a duration. These pairings resulted in a total of 12 sample conditions, as seen in Table 4.1 below.

Experiment 4 Sample Conditions			
Sample condition number	Sample Display	Replication Display	Duration (seconds)
1	3	Brown rectangle	5.5
2	3	Brown rectangle	11.5
3	12	Brown rectangle	5.5
4	12	Brown rectangle	11.5
5	21	Brown rectangle	5.5
6	21	Brown rectangle	11.5
7	B	Brown rectangle	5.5
8	B	Brown rectangle	11.5
9	IJ	Brown rectangle	5.5
10	IJ	Brown rectangle	11.5
11	TI	Brown rectangle	5.5
12	TI	Brown rectangle	11.5
Sample Size = 16			

Table 4.1

For each trial the subject would see either one of the sample displays, as seen in table 4.1 above. At the end of a trial, the subject would be asked to reproduce the sample display by starting a replication display and terminating the display when they judged that the duration matched that of the sample display. Each trial consisted of one sample condition. Each sample condition was displayed a total of eight times throughout the experiment. All of the sample conditions were displayed in a random order throughout the experiment.

2.3.5 Experiment 5

The results of experiment 4 showed the expected separation of mean ratios in the shorter duration but not the longer duration. As a small anchoring effect may be disguised by the greater response variability at longer durations in this experiment we used durations (3.5 seconds and 8.5 seconds) that branched the shorter duration (5.5 seconds) in experiment 4. The numbers used were 3, 12, and 21. The letters used were B, IJ, and TI. Each number and letter were paired with a duration. These pairings resulted in a total of 12 sample conditions, as seen in Table 5.1 below.

Experiment 5 Sample Conditions			
Sample condition number	Sample Display	Replication Display	Duration (seconds)
1	3	Brown rectangle	3.5
2	3	Brown rectangle	8.5
3	12	Brown rectangle	3.5
4	12	Brown rectangle	8.5
5	21	Brown rectangle	3.5
6	21	Brown rectangle	8.5
7	B	Brown rectangle	3.5
8	B	Brown rectangle	8.5
9	IJ	Brown rectangle	3.5
10	IJ	Brown rectangle	8.5
11	TI	Brown rectangle	3.5
12	TI	Brown rectangle	8.5
Sample Size = 16			

Table 5.1

For each trial the subject would see either one of the sample conditions, as seen in table 5.2 above. At the end of a trial, the subject would be asked to reproduce the symbol’s duration. Each trial consisted of one sample condition. Each sample condition was displayed a total of eight times throughout the experiment. All of the sample conditions were displayed in a random order throughout the experiment.

2.3.6 Experiment 6

Experiments one and two used a block design whereas in experiments three and five the stimulus conditions were randomly presented. It is important to test the effect of numerical magnitude on temporal estimations with the block design in second timing, as no significant results were found with the previous experimental designs for second timing but significant results were found in the block design for millisecond timing. To test whether a blocked design is critical to reveal the anchoring effect we conducted an experiment similar to experiments 3 and 4 with a blocked design. The durations used in this experiment were 3.5 seconds, 8.5 seconds, and 11.5 seconds. The numbers used when the duration was set were 1, 5, and 9. The number used when the participant reproduced the duration was 5. Each number was paired with duration in a block design, which resulted in a total of 9 sample conditions across 3 blocks as seen in Table 6.1 below. All of the sample conditions used the number 5 when the participant reproduced the duration.

Experiment 6 Sample Conditions				
Block	Sample condition	Sample Display	Replication Display	Duration
1	1	1	5	3.5
1	2	1	5	8.5
1	3	1	5	11.5
2	4	5	5	3.5
2	5	5	5	8.5
2	6	5	5	11.5
3	7	9	5	3.5
3	8	9	5	8.5
3	9	9	5	11.5
Sample Size = 11				

Table 6.1

Presentation order was counter balanced. The even numbered subjects would see block one first, block two second, and block three last. The odd numbered subjects would see block three first, block two second, and block one last. The sample conditions for each block were displayed a total of eight times. Each sample condition within each block was displayed randomly throughout that block. At the end of each trial the subject would be asked to replicate the duration of the symbol just seen. This replication was done with the number 5.

3. Results

Experiments 1 and 2 were discrimination tasks asking for a judgment as to whether the comparison display was longer or shorter than the sample display. These experiments were analyzed using percent judged longer. Experiments 3 through 6 measure participants reproduced duration with a reproduction task. The primary dependent variable was the ratio of the reproduced duration to the sample duration.

The results of all of the experiments are represented graphically. The expected results for the numerical version of experiments 3 through 6 would be to see a separation of the functions relating mean ratios to sample durations for the three anchor conditions with anchor 3 having the largest mean ratio and anchor 1 having the smallest mean ratio. The expected results for the numerical versions of experiments 1 and 2 would be to see a separation between the percent longer values of all of the blocks. The block comparing 9 and 5 should have the highest percentage of longer judgments. The block comparing 1 and 5 should have the lowest percentage of longer judgments. The letter versions of all experiments are not expected to show the separation between the numerical values, as the letter versions are measures of control.

The results would then be tested for significance, using an analysis of variance (ANOVA) statistical test. The results would be considered significant if they have a p-value of 0.05 of less, meaning that the results are unlikely to have occurred by chance.

3.5 Experiment 1

It is apparent from Figure 1.1 that there is a difference between the percent longer values of the different numerical blocks. There is no apparent difference between the percent longer values of the different letter blocks in Figure 1.2. The significant main effect of number percent longer judgments ($F(2,32) = 4.467$, $p = 0.019$, $\eta_p^2 = 0.218$) mean that numbers do alter the perception of time in this experiment. The non-significant main effect of letter percent longer judgments ($F(2,32) = 1.206$, $p = 0.313$, $\eta_p^2 = 0.070$) mean that letters do not alter the perception of time in this experiment.

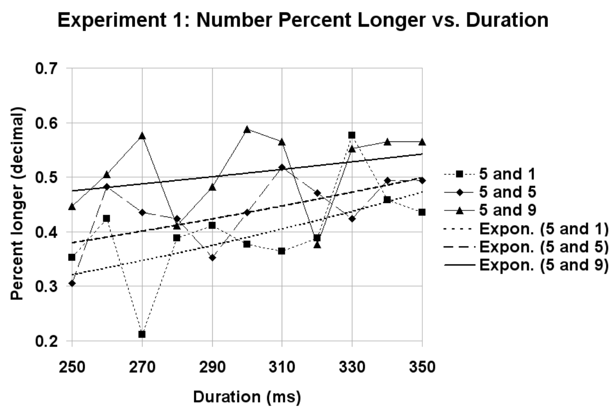

Figure 1.1

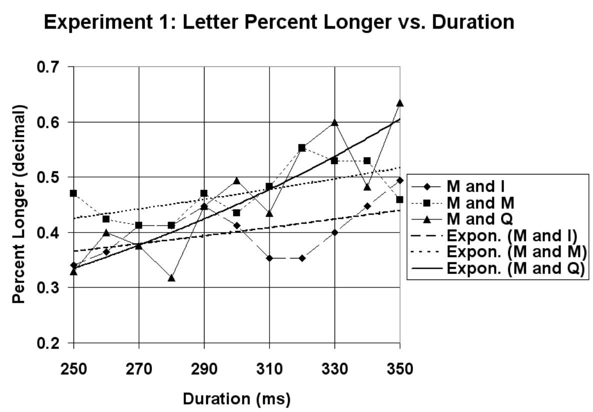

Figure 1.2

3.6 Experiment 2

It is not apparent from Figure 2.1 that there is a difference between the percent longer values of the different blocks. The non-significant main effect of number percent longer judgments (F(2,20) = 2.385, p = 0.118, η_p^2 = 0.193) mean that numbers do not alter the perception of time in this experiment.

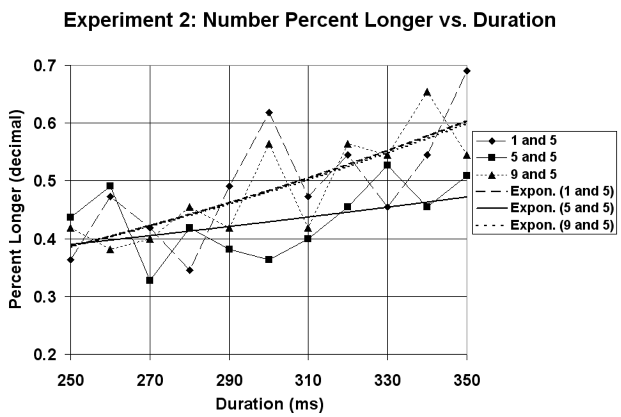

Figure 2.1

3.2 Experiment 3

In Figure 3.1 the expected separation of mean ratios for the different numerical anchors is not seen for either the duration of 5.5 seconds or the duration of 11.5 seconds, and resembles the lack of effect on the letter display (Figure 3.2). The non-significant main effect of number mean ratios (F(2,30) = 2.467, p = 0.102, η_p^2 = 0.140) mean that numbers do not alter the perception of time in this experiment. The non-significant main effect of letter mean ratios (F(2,30) = 1.381, p = 0.267, η_p^2 = 0.083) mean that letters do not alter the perception of time in this experiment.

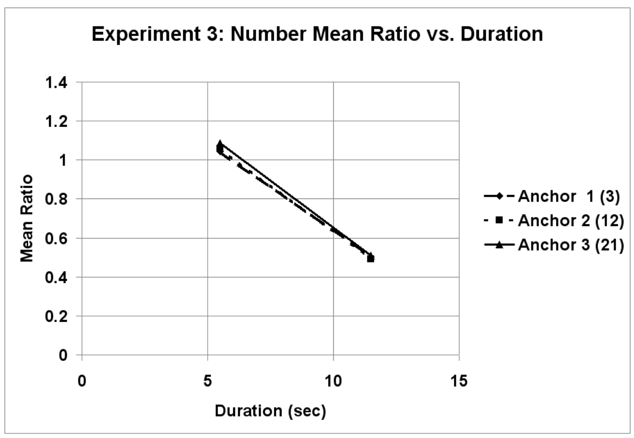

Figure 3.1

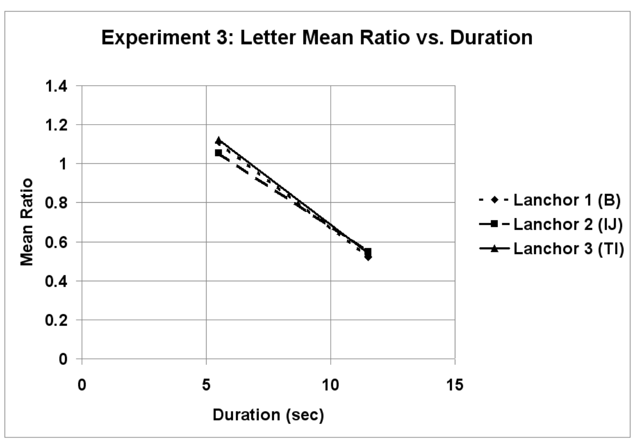

Figure 3.2

3.1 Experiment 4

In Figure 4.1 the expected separation of mean ratios is seen for the duration of 5.5 seconds but not for the duration of 11.5 seconds. The separation expected is not seen for the letter condition (Figure 4.2). The non-significant main effect of number mean ratios ($F(2,30) = 3.099$, $p = 0.060$, $\eta_p^2 = 0.172$) mean that numbers do not alter the perception of time in this experiment. The difference between the short and long durations is shown by a significant interaction between numerical anchor and duration ($F(2,30) = 5.000$, $p < 0.020$, $\eta_p^2 = 0.250$) The non-significant main effect of letter mean ratios ($F(2,30) = 0.124$, $p = 0.884$, $\eta_p^2 = 0.009$) mean that letters do not alter the perception of time in this experiment.

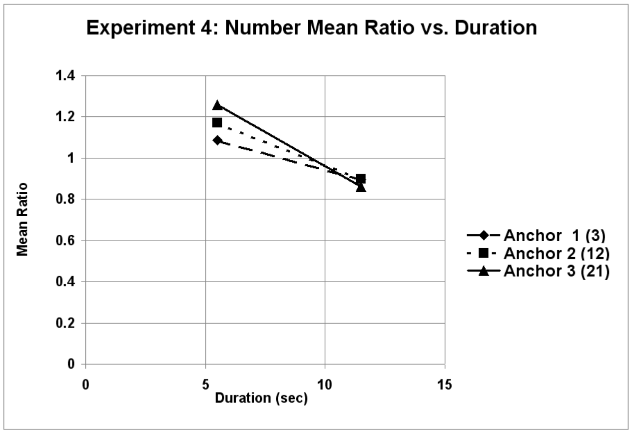

Figure 4.1

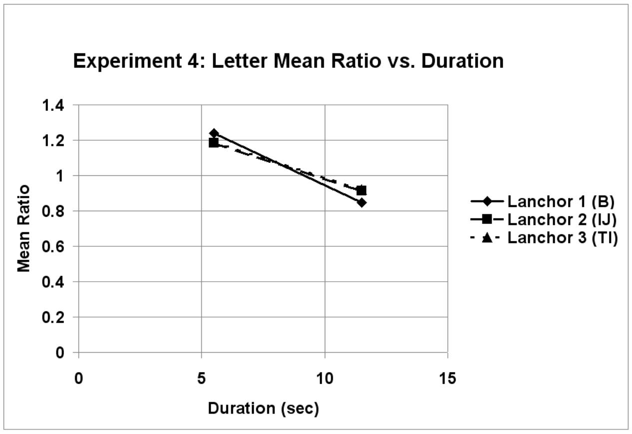

Figure 4.2

3.3 Experiment 5

In Figure 5.1 the expected separation of mean ratios is not seen for either the duration of 3.5 seconds or the duration of 8.5 seconds. The separation expected is not seen for the letter condition (Figure 5.2).The non-significant main effect of number mean ratios ($F(2,30) = 1.547$, $p = 0.229$, $\eta_p^2 = 0.093$) mean that numbers do not alter the perception of time in this experiment. The non-significant main effect of letter mean ratios ($F(2,30) = 0.148$, $p = 0.863$, $\eta_p^2 = 0.011$) mean that letters do not alter the perception of time in this experiment.

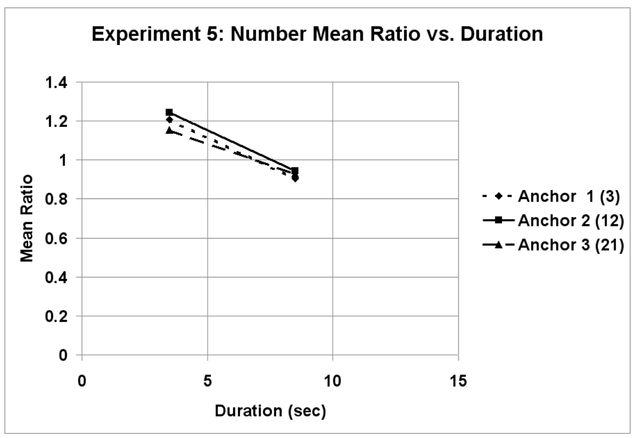

Figure 5.1

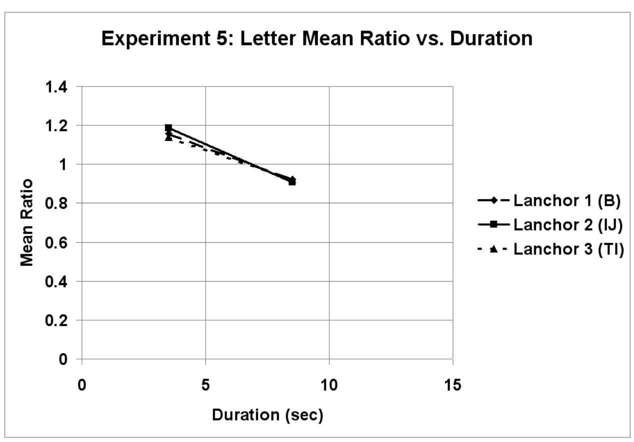

Figure 5.2

3.4 Experiment 6

In Figure 6.1 the expected separation of mean ratios is not seen for either the durations of 3.5 seconds, 8.5 seconds, or 11.5 seconds. The non-significant main effect of number mean ratios ($F(2,20) = 2.682$, $p = 0.093$, $\eta_p^2 = 0.212$) mean that numbers do not alter the perception of time in this experiment.

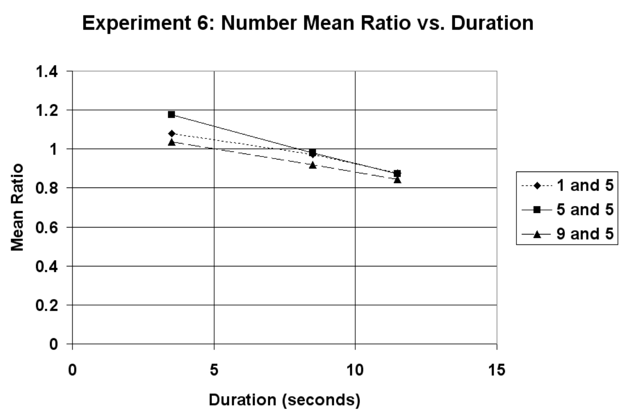

Figure 6.1

Discussion

It has already been shown that numbers and time can be processed simultaneously and that they both may use the same pathways. It has even been shown that numbers can alter the perception of millisecond timing. These experiments further support the idea that numbers can alter the perception of millisecond timing. These experiments do not support the idea that numbers can alter the perception of second timing.

Out of all of the experiments, only the reproduced millisecond task with anchors as the comparison display showed significant main effects ($F(2,32) = 4.467$, $p = 0.019$, $\eta_p^2 = 0.218$). This could mean that numerical anchors may only affect the immediate perception of a duration and not the memory of a duration, as the sample display is stored in memory and the comparison display is immediately perceived. It is also possible that time perception is affected only by blocked millisecond tasks using an anchor as the comparison display.

The second timing experiments did not show significant main effects. This could be because numbers do not affect second timing systems or because the effect seen at the millisecond level may be too small to see at longer durations. If numerical anchors do not affect second timing but do affect millisecond timing, then it can be assumed that millisecond timing and second timing use different processes, which would support the idea that they are separate systems. If the effect seen at the millisecond level is too small to see at longer durations then it cannot be assumed that they are separate systems based on this research. Within the second experiments there were no differing effects between the sample and reproduction displays, no differing effects between the blocked and unblocked experimental designs, and no differing effects in the shorter and longer durations tested.

It is possible that no evidence was found in support of numbers altering second timing, because the millisecond timing experiments done in this study had different experimental designs than the second timing experiments done in this study. The millisecond timing experiments used a comparison task whereas the second timing experiments used a replication task. It is possible that the type of task combined with number perception could alter time perception, instead of just number perception altering time perception.

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